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In This Issue

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CIRCULAR TRACK TESTS ON LOW-COST BITUMINOUS MIXTURES

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

Reported by C. A. CARPENTER, Associate Civil Engineer, and J. F. GOODE, Junior Highway Engineer

THE small indoor circular track and the device for applying traffic in making laboratory tests on bituminous surfaces were briefly described in the January 1934 issue of PUBLIC ROADS. This apparatus is being used in the Bureau's laboratory at the Arlington Experiment Farm near Washington to study the various factors that influence the behavior of bituminous road-surfacing mixtures.

The test track, shown in figure 1, is laid in a circular concrete trough 12 feet in mean diameter, 18 inches wide, and 12½ inches in mean depth. The track consists of a base course of gravel, crushed stone, or other suitable material and a wearing course of the bituminous surfacing material to be tested. The surface may be tested dry or the base and also the surface may be flooded or maintained in a moist condition through capillarity by introducing water from a concentric water trough through perforations at the base of the inner curb.

Two automobile wheels, equipped with 20 by 6.00 low-pressure tires and mounted on the ends of a centrally pivoted steel beam, are used for compacting both base and surface and for testing the surface course. The beam is rotated by a motor-driven vertical shaft and operating speeds of 4½, 6, and 9 miles per hour are obtained by the use of a three-step cone pully transmission. The entire weight of the wheel and beam assembly, amounting to approximately 800 pounds per wheel, is imposed on the track.

Distribution of this "traffic" over the entire width of the track during compaction is accomplished by slowly shifting the pivotal point of the beam back and forth through a distance of 18 inches by means of a hand-operated wheel. Although mounted on the rotating beam, this wheel may be operated while the beam is in motion. For compacting, the operating speed is maintained at 4½ miles per hour.

For testing the compacted wearing course, the pivotal point of the beam is set and clamped 2½ inches off center so that the wheels travel in two concentric lanes 5 inches apart. This accelerates the test to some extent by concentrating the traffic and producing a transverse kneading action between the two wheel tracks. The maximum operating speed of 9 miles per hour is maintained during testing.

ONE TYPE AND GRADING OF AGGREGATE USED IN ALL MIXTURES

This report describes the use of this apparatus in studying the road-mix or oil-processed gravel type of surfacing widely used in the Western States. Tests were conducted to determine the effect of variations in the quantity and consistency of the bituminous material and the effect of water in the surfacing mixture, in the base, and in both base and surfacing mixture. The density and percentage of voids in the traffic-compacted mixtures, both before and after testing, were determined and specimens of the freshly prepared mixtures were also compacted by various other methods for comparative density studies.

Most of the experimental surfacing mixtures were laid on a sand-clay-gravel base course of the type commonly used in the Western States for road-mix construction. The introduction of water into the base course incident to saturating the surface mixture produced simultaneous failure of both the base and bituminous surface. Therefore, in order to eliminate the effect of base failure, a more rigid type of base course was substituted for the sand-clay-gravel in testing the surfacing mixtures on a wet base.

One type and grading of aggregate was used in all of the surface mixtures discussed in this report. It consisted of 54 percent of crushed Potomac River gravel, 31 percent of Potomac River concrete sand, and 15 percent of local silty soil. The gravel was of good quality and was coarse enough to provide a crushed product of high angularity. It was crushed to pass the 1-inch screen, and 95 percent by weight of the crushed product had two or more fractured faces to the fragment. The filler material was a local silty clay soil that was dried and pulverized to pass the no. 40 sieve. Soil tests on this material gave the following results:

Amount passing the no. 200 sieve, percent	60
Clay content, percent	26
Liquid limit	23
Centrifuge moisture equivalent	20
Plasticity index	7

The aggregate for each mixture was carefully proportioned to conform closely to the grading shown in table 1.

TABLE 1.—*Grading of aggregates used in bituminous mixtures tested on the circular track*

Passing—	Retained on—	Percent
	1-inch screen	1.1
1-inch screen	¾-inch screen	5.7
¾-inch screen	½-inch screen	16.3
½-inch screen	¼-inch screen	17.0
¼-inch screen	No. 10 sieve	12.4
No. 10 sieve	No. 20 sieve	10.8
No. 20 sieve	No. 30 sieve	6.0
No. 30 sieve	No. 40 sieve	5.4
No. 40 sieve	No. 50 sieve	4.2
No. 50 sieve	No. 80 sieve	5.4
No. 80 sieve	No. 100 sieve	1.7
No. 100 sieve	No. 200 sieve	3.5
No. 200 sieve		10.5

Five "straight steam-and-fire reduced" asphaltic residual oils were used throughout this series of tests. All were produced from the same crude oil and by the same refiner. The results of laboratory tests on these five materials are given in table 2. Materials A, B, C, and D conformed approximately to the slow-curing, liquid, asphaltic materials of the grades SC–1, SC–2, SC–3, and SC–4, respectively, as defined in the recommended specifications of the Bureau and the Asphalt Institute. Material E was a semisolid asphaltic residue similar to that commonly referred to as 94+ asphaltic road oil. The consistencies of these materials, measured by their float time at 122° F., were 10, 16, 27, 37, and 170, as shown in table 2.

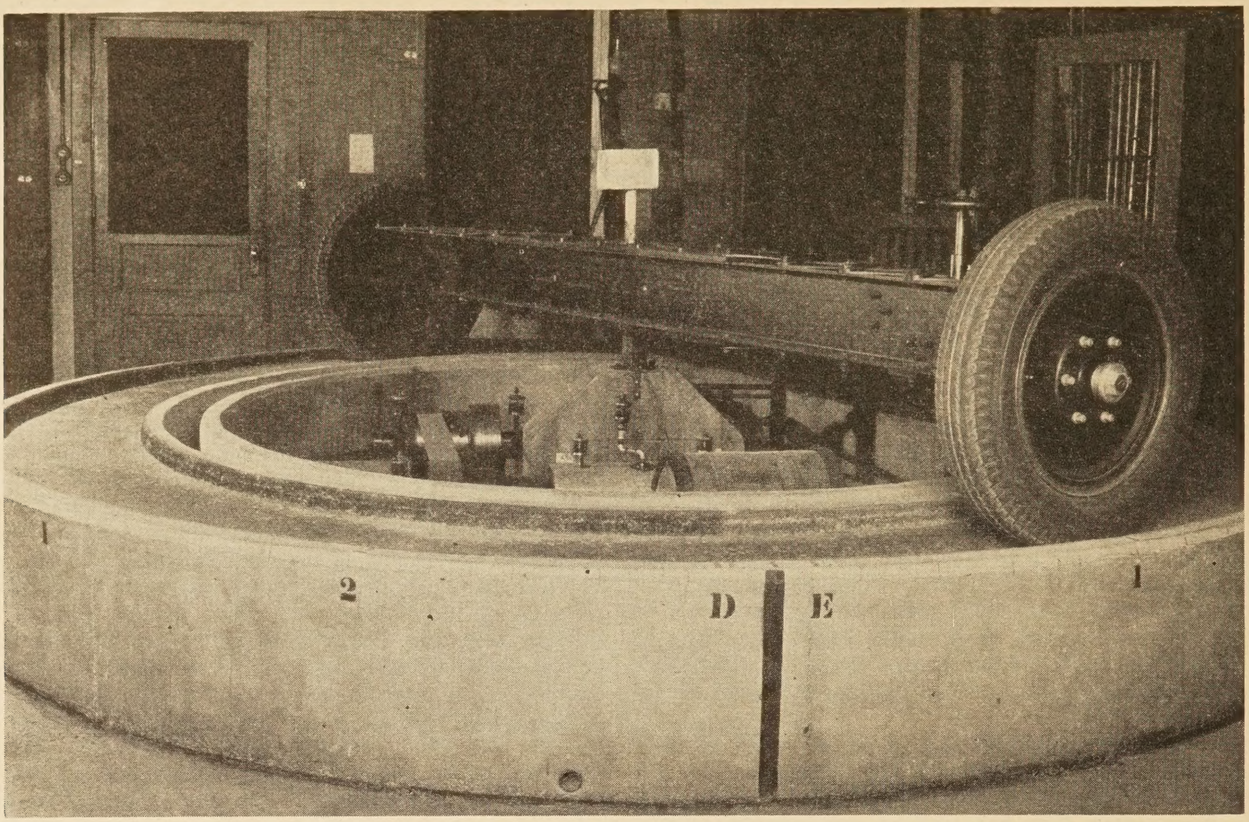


FIGURE 1.—THE CIRCULAR TEST TRACK AND TESTING APPARATUS. THE WHEELS ARE RESTING ON A COMPACTED GRAVEL BASE COURSE.

TABLE 2.—*Results of tests on bituminous materials*

	Test results for materials—				
	A	B	C	D	E
Flash point, °F	300	295	310	310	490
Specific gravity, 77° F./77° F	0.952	0.972	0.976	0.985	1.006
Saybolt-Furol viscosity at 122° F., seconds	84	290	780	1,311	--------
Saybolt-Furol viscosity at 140° F., seconds	--------	--------	335	527	--------
Penetration, 100 grams, 5 seconds, 77° F	--------	--------	--------	--------	338
Float at 122° F., seconds	10	16	27	37	170
Total distillate to 437° F., percent by volume	0	0	0	0	0
Total distillate to 600° F., percent by volume	0.5	0.5	0.5	0	0
Total distillate to 680° F., percent by volume	11.0	13.0	7.0	6.0	0
Float of residue at 122° F., seconds	20	39	48	55	176
Solubility of residue in CS_2, percent	99.95	99.95	99.92	99.91	99.90
Residue of 100 penetration, percent	52	63	70	75	93

TESTS CONDUCTED TO DETERMINE THE EFFECT OF VARIATIONS IN QUANTITY AND CONSISTENCY OF THE BITUMINOUS MATERIAL

In conducting the tests on the water-free mixtures, the circular track was divided into five equal sections or one for each of the five grades of bituminous material. In each group of tests all five sections contained the same percentage of bitumen by volume. Five tracks were laid and tested, each track containing a different percentage of bitumen by volume. The percentages used, calculated on both a weight and volume basis, are given in table 3. In the following discussion all the mixtures in track 1 will be referred to as 3½-percent mixtures, those in track 2 as 4-percent mixtures, etc., and the various sections will be designed by the identification letter of the contained bitumen and the percentage of bitumen in the mixture. For instance, the section of track 1 containing material A will be referred to as section A–3½.

TABLE 3.—*Percentages of bituminous material used in determining the effect of quantity and consistency of the bituminous material on the performance of bituminous mixtures*

Bituminous material		Amount of bituminous material in mixtures, by weight				
Identification	Float at 122° F.	Track 1 (9.1 percent by volume)	Track 2 (10.3 percent by volume)	Track 3 (11.5 percent by volume)	Track 4 (12.7 percent by volume)	Track 5 (13.9 percent by volume)
		Percent	*Percent*	*Percent*	*Percent*	*Percent*
A	10	3.5	4.0	4.5	5.0	5.5
B	16	3.6	4.1	4.6	5.1	5.6
C	27	3.6	4.1	4.6	5.1	5.6
D	37	3.6	4.1	4.7	5.2	5.7
E	170	3.7	4.2	4.7	5.3	5.8

About 400 pounds of each mixture was prepared, which provided enough material to lay a section 7.4 feet long and 2½ inches in compacted depth, and also provided sufficient excess material for all other tests performed on the mixture. The mixtures were prepared by hand mixing with rakes and spades in a shallow iron pan. The aggregate and bituminous material were warmed to facilitate mixing, and for material E it was necessary to heat both the stone and the bituminous material to approximately 250° F. to obtain satisfactory mixing. All mixtures except those containing material E were laid at air temperature. The E mixtures were laid at approximately 150° F., and in building each track the E mixture was laid last in order that compaction might be started while it was still at approximately that temperature.

The mixtures were placed in two layers each slightly less than 2 inches in loose thickness. The first layer was compacted by about 100 wheel trips distributed

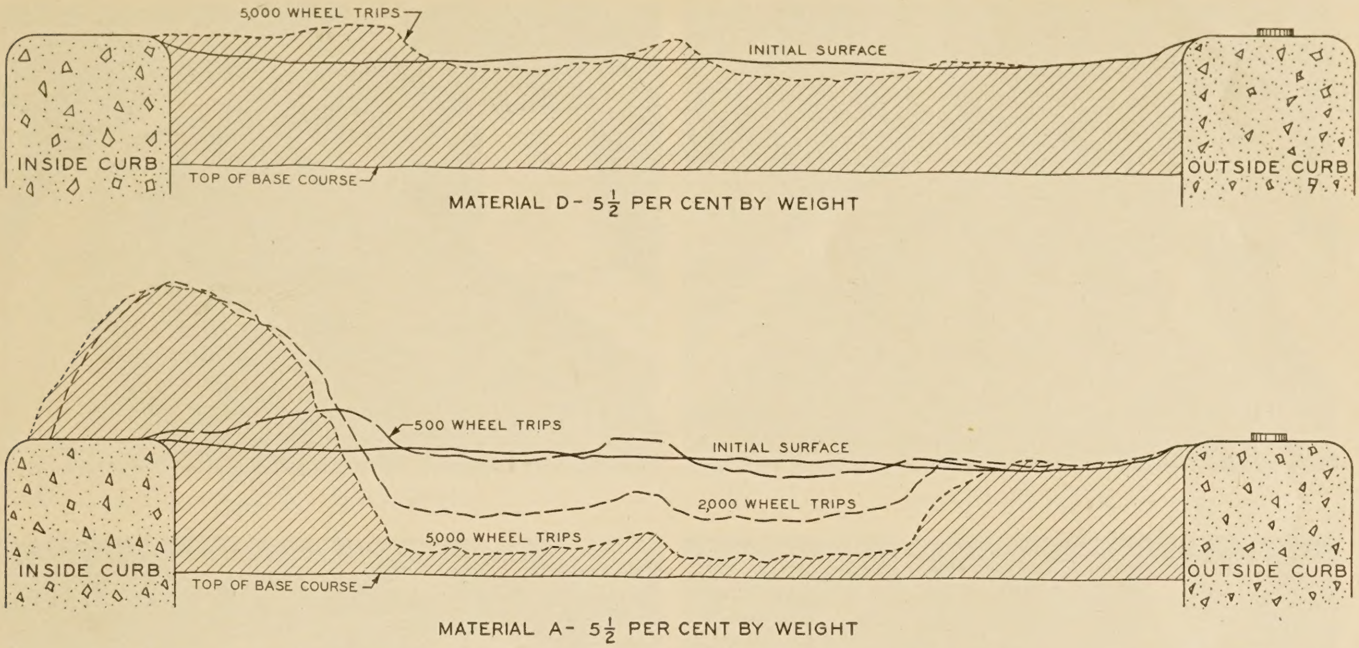


FIGURE 2.—TYPICAL TRANSVERSE PROFILES FROM CIRCULAR TRACK SHOWING PROGRESSIVE RUTTING OF BITUMINOUS MIXTURES UNDER TRAFFIC.

over the 18 inches of track width, the compaction being held to a minimum in order to prevent the formation of a seal and resulting plane of weakness between the first and second layers. The second layer was then spread and leveled by raking and troweling, tamped with 50-pound hand tamping irons, and brushed with a hand brush to fill surface voids. Compaction was then completed by distributing the traffic of the rubber-tired wheels traveling at a speed of approximately 4½ miles per hour.

Compaction with the rubber-tired wheels was continued as long as any subsidence of the surface of any section as a whole could be produced. This required from 3,500 to 4,500 wheel trips distributed over the 18-inch track, the number of trips required to compact to "refusal" depending upon the richness of the mixtures. The lean mixtures required more traffic for compacting than did the rich ones.

Subsidence of the surface during compacting and vertical displacement during testing were measured by means of a recording profilometer, the feet of which rested on permanent brass plugs set in the curbs. Transverse profiles were taken at frequent intervals both during compacting and testing. Each section of surfacing was provided with two sets of base plugs for taking transverse profiles. Two typical series of these profiles, as traced from the original record sheets, are shown in figure 2. Figure 3 shows the profilometer with a record sheet in place.

The testing of each section for stability and resistance to wear was started as soon as compaction was completed, the beam being locked in testing position 2½ inches off center so that the wheels traveled in two concentric circular paths 5 inches apart. As ruts were formed in the less stable mixtures, ridges of displaced material were pushed up toward the two curbs. Figure 4 illustrates the appearance of some of the sections while testing was in progress.

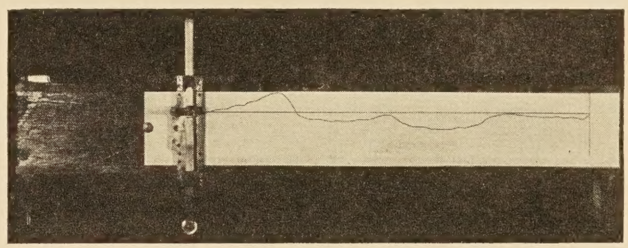
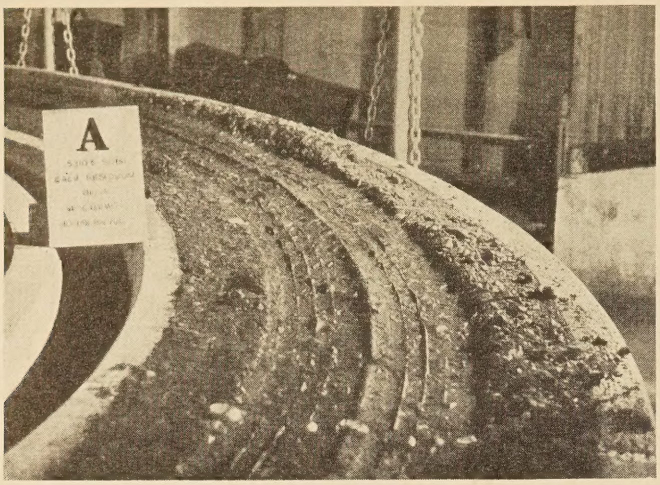


FIGURE 3.—THE RECORDING PROFILOMETER WITH RECORD SHEET IN PLACE.

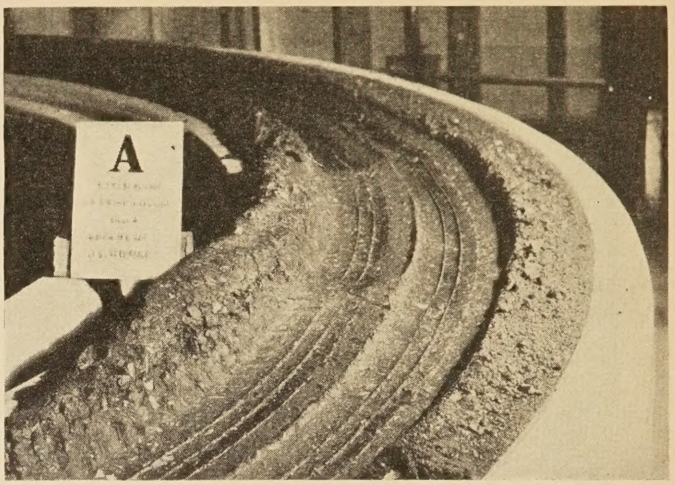
MIXTURES WITH HIGH-VISCOSITY BITUMINOUS MATERIALS HAD GREATEST STABILITIES

In figure 4 it will be noted that section A–4, although not lacking in stability, showed serious raveling, indicating insufficient bituminous material to bond the aggregate, while section A–4½ showed rutting and shoving, indicating an excess of bitumen. Section B–4 was typical of the remainder of the 4-percent mixtures, which retained smooth, even surfaces throughout the test. Section B–4½ showed considerable rutting and shoving, indicating excessive bitumen and illustrating the necessity of closely controlling the bitumen content. Comparison of C–4½ with B–4½ illustrates the effect of greater consistency of the bituminous material in reducing the tendency of the richer mixtures to shove and rut. However, in section C–5 instability was indicated by rutting, showing an excess of bitumen.

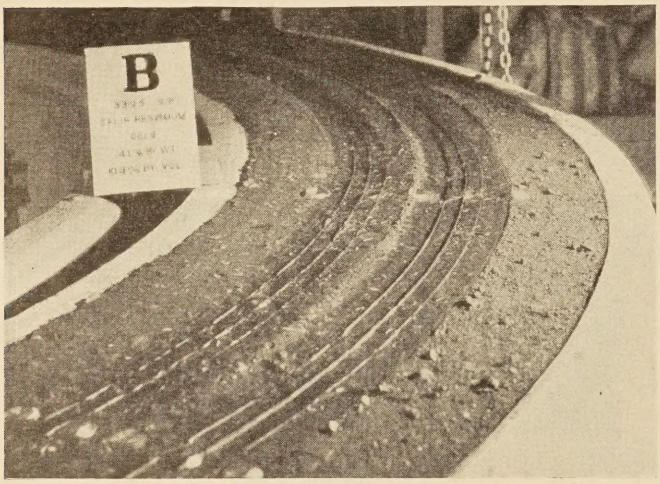
In calculating the average vertical displacement of the surface, the cross-sectional area of the ruts and the cross-sectional area of the ridges, in square inches, were measured from the profiles with a planimeter. The total of these areas divided by the width of the track (18 inches) gave the average vertical displacement. Figure 5 shows vertical displacement plotted against amount of traffic for all consistencies and proportions of bituminous materials tested. The relation of average vertical displacement to consistency and



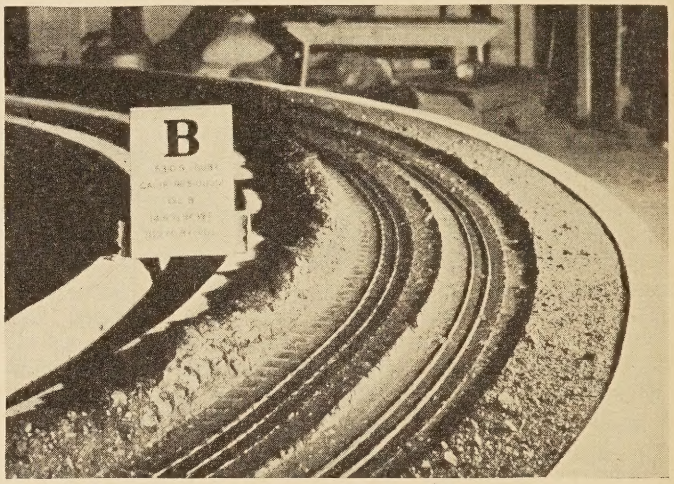
SECTION A-4



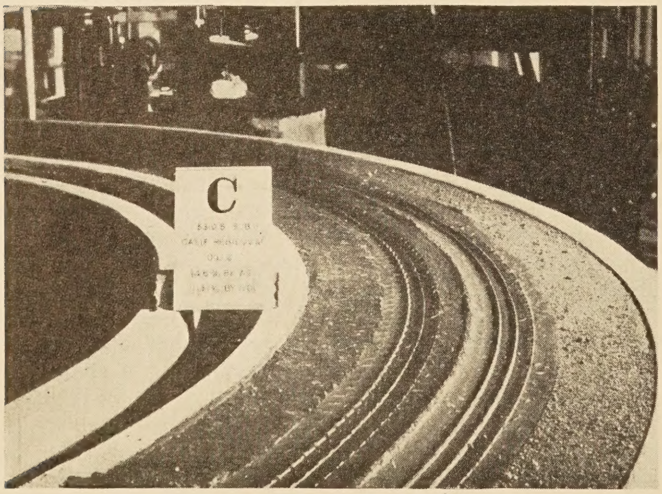
SECTION A-4½



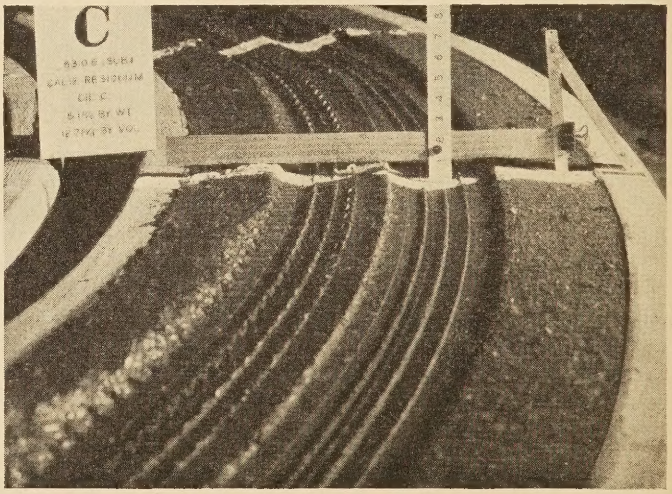
SECTION B-4



SECTION B-4½



SECTION C-4½



SECTION C-5

Figure 4.—Appearance of Some of the Bituminous Mixtures During Testing.

amount of bitumen is shown in figure 6, which was developed by taking vertical displacement at 5,000 trips from figure 5 and plotting it against percentage of bitumen in the mixture. Brass plugs were set in the surfaces and observed for forward movement of the surfacing material. Measurements showed that shoving was, in general, proportional to vertical displacement. Vertical and longitudinal displacements and numerical ratings of the test mixtures on the basis of both are given in table 4.

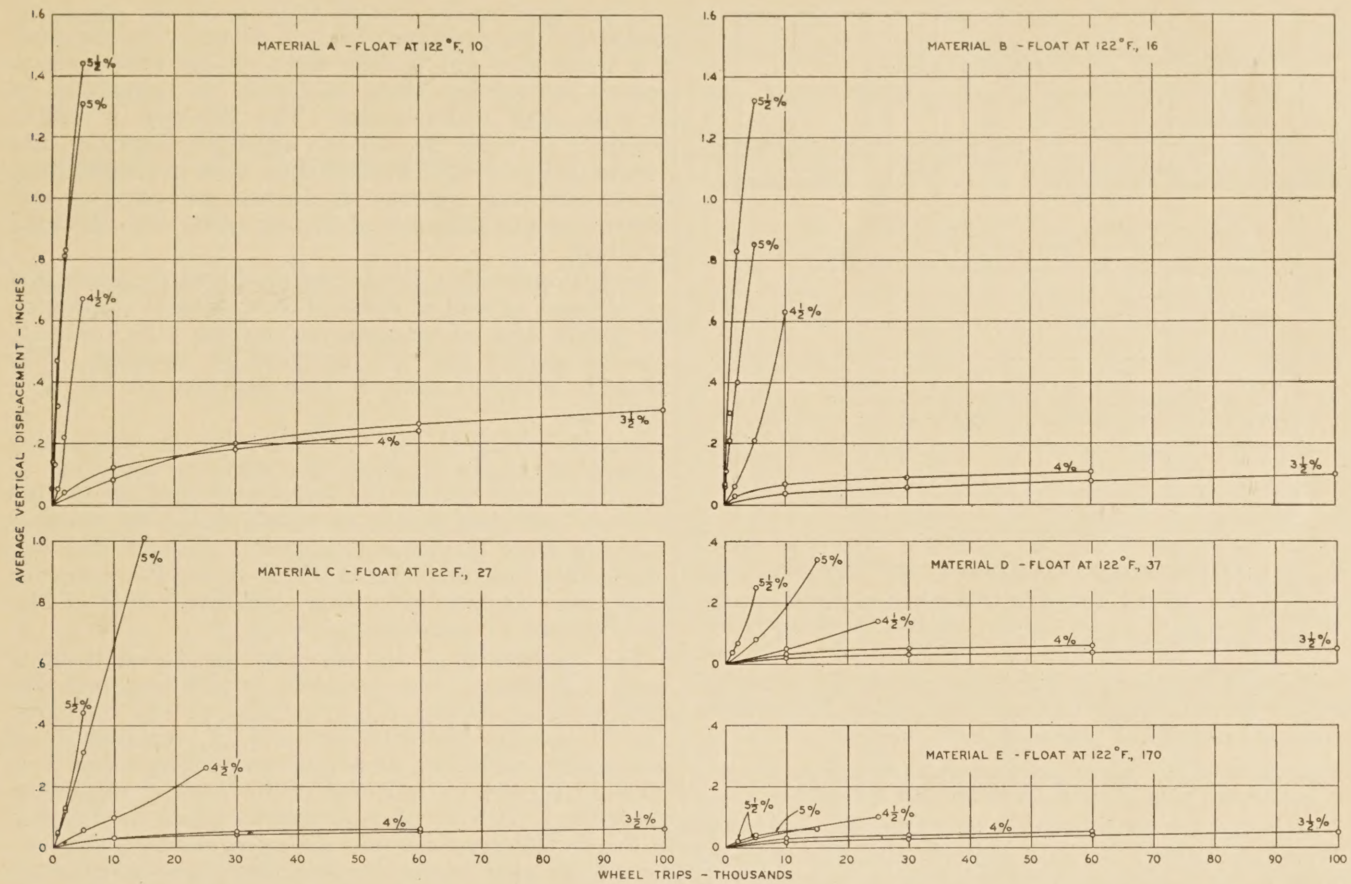


FIGURE 5.—RELATION OF VERTICAL DISPLACEMENT TO NUMBER OF WHEEL TRIPS FOR VARIOUS KINDS AND PERCENTAGES OF BITUMEN. APPROXIMATE PERCENTAGES OF BITUMEN BY WEIGHT OF MIXTURES ARE SHOWN ON INDIVIDUAL CURVES.

TABLE 4.—*Stability and rating of mixtures as measured by vertical displacement and by longitudinal displacement*

Mixture identification	Rutting caused by first 5,000 wheel trips		Shoving caused by 2,000 wheel trips	
	Vertical displacement	Rating	Horizontal displacement	Rating
	Inches		*Inches*	
E-3½	0.01	1	0	1
E-4	.01	1	0	1
D-3½	.01	1	0	1
D-4	.01	1	0	1
D-4½	.01	1	.01	2
C-3½	.02	2	0	1
C-4	.02	2	0	1
B-3½ [1]	.02	2	0	1
E-4½	.03	3	0	1
E-5	.03	3	0	1
E-5½	.03	3	0	1
A-3½ [1]	.04	4	0	1
C-4½	.05	5	.14	4
B-4	.06	6	0	1
D-5	.08	7	.04	3
A-4 [1]	.08	7	.01	2
B-4½	.23	8	.56	6
D-5½	.24	9	1.20	7
C-5	.31	10	.25	5
C-5½	.44	11	2.16	10
A-4½	.67	12	1.36	8
B-5	.85	13	1.68	9
A-5	1.31	14	3.24	11
B-5½	1.32	14	8.00	12
A-5½	1.44	15	11.00	13

[1] Failed by surface raveling.

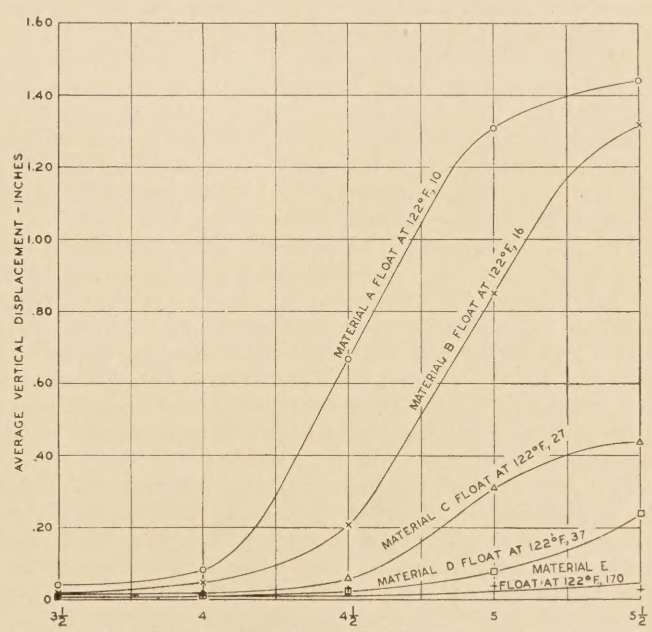


FIGURE 6.—RELATION OF CONSISTENCY AND PERCENTAGE OF BITUMEN TO VERTICAL DISPLACEMENT AFTER THE FIRST 5,000 WHEEL TRIPS.

The amounts of vertical and longitudinal displacement of the surface, given in table 4 and shown graphically in figures 5 and 6, give an excellent indication of the relative stability or resistance to plastic flow of the mixtures under moving wheel loads. The untreated sand-clay-gravel base [1] and all of the sections of oil-processed surface containing up to 4 percent of bituminous material showed a high degree of resistance to

[1] No measurements of displacement are given on the untreated base, since no measurable shoving or rutting occurred.

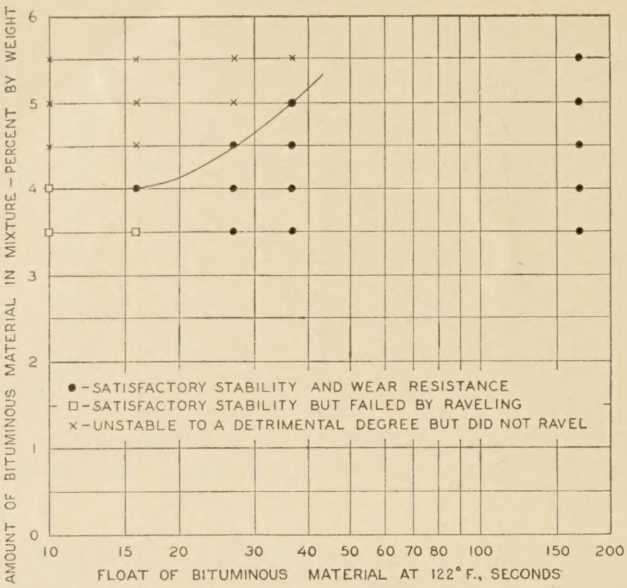


FIGURE 7.—RELATIONS BETWEEN CONSISTENCY AND QUANTITY OF BITUMEN IN THE 25 TEST MIXTURES AND THEIR CONDITION AFTER 5,000 WHEEL TRIPS.

vertical and longitudinal displacement, as did a limited number of the richer mixtures in which the heavier grades of bituminous material were used.

EXCESS OF BITUMEN MOST DETRIMENTAL IN MIXTURES CONTAINING LOW-VISCOSITY BITUMINOUS MATERIALS

Purely from a consideration of resistance to internal movement or flow, the data indicate that the effect of adding liquid bituminous material to the aggregate is to reduce its stability. While this reduction in stability is not particularly detrimental until the bitumen content of the mixture reaches a certain critical percentage, the reduction takes place very rapidly after the critical percentage has been exceeded. It is apparent that this critical percentage was not reached for the semisolid material E. The data also indicate that a large loss of stability is caused by a relatively small excess of the light material A, while the more viscous materials permit the use of proportionately higher percentages of bitumen before the critical point is reached.

Figure 7 shows relations between the variables in the 25 mixtures tested. The abscissae are consistencies of the bituminous materials plotted on a logarithmic scale and the ordinates are percentages of bituminous material in the mixtures. The curve connecting the points representing the richest stable mixtures for the respective grades of bituminous material is the approximate upper oiling limit for the materials and conditions of these tests.

The mixtures whose behavior and appearance under the concentrated traffic test showed satisfactory stability were found to have had average vertical displacements of 0.1 inch or less after 5,000 wheel trips. The minimum average vertical displacement for any section was 0.01 inch and the maximum for the 16 sections having satisfactory stability was 0.08 inch. These are the first 16 sections listed in table 4. The remaining nine mixtures showed much greater vertical displacements accompanied by indications of distress such as corrugations and cracks in the surfaces. For these nine sections the average vertical displacement ranged from 0.23 inch to 1.44 inches.

In considering the loss of stability of the aggregate caused by the addition of liquid bituminous material, it is important not to lose sight of the very definite reasons for adding these materials to aggregates in low-cost road construction. The bitumen is added primarily to bond the surface aggregate together into a more or less tough, flexible skin, thus preventing the loss of surfacing material by dusting and raveling and preventing the entrance of surface water into the road structure.

In this connection, it was observed that the untreated gravel base, as well as three of the mixtures containing low percentages of bitumen and having high stability, showed serious loss of material by raveling. The mixtures failing in this way were mixtures A–3½, A–4, and B–3½.

Results obtained for the five mixtures containing material B clearly illustrate the effect of variations in quantity of bitumen on the serviceability of the treated surface. Mixture B–3½, as noted, failed by raveling resulting from insufficient bitumen; mixture B–4 was satisfactory; and mixtures B–4½, B–5, and B–5½ showed progressive degrees of rutting, indicating lack of stability caused by overoiling.

The consistency of the bitumen was found to be of more importance than quantity in affecting both the stability and sealing characteristics of the mixtures. Use of the low-viscosity material, A, resulted in no satisfactory mixtures, these mixtures failing either from raveling caused by leanness or by rutting caused by overoiling. Use of the next heavier grade, B, resulted in one satisfactory mixture with 4 percent of bitumen; use of the next grade, C, produced three satisfactory mixtures, namely, those containing 3½, 4, and 4½ percent of bitumen; and material D was satisfactory in four percentages, from 3½ to 5, inclusive, and showed low stability only in mixture D–5½.

It is evident from the test data that the use of a low-viscosity material requires the imposition of extremely close limits on the permissible bitumen content of the mixture, while the use of more viscous materials allows a much wider variation in bitumen content without sacrificing either stability or wear resistance.

DENSITY OF MIXTURES AFFECTED BY METHOD OF COMPACTION AND AMOUNT AND CONSISTENCY OF BITUMEN

Determinations of density and percentage of voids were made on all of the mixtures tested. These determinations were made on specimens taken from the track surface after compaction under distributed traffic and also on specimens taken from ruts after the completion of the concentrated traffic tests. In addition, specimens of each mixture were compacted in the Bureau's molding machine [2] by rolling 1 minute with a load of 200 pounds per linear inch of roller width and 4 additional minutes with a load of approximately 400 pounds per inch of roller width. Densities and percentages of voids were determined on these specimens, as well as on specimens compacted in a 6-inch cylindrical mold by 100 blows of a 3-pound mallet.[3] Table 5 gives the results of the density tests on the mixtures as compacted by the various methods.

[2] See A Machine for Molding Laboratory Specimens of Bituminous Paving Mixtures, by J. T. Pauls, PUBLIC ROADS, vol. 10, no. 2, April 1929.

[3] Method described in The Road-Mix Manual, no. 1, issued by the Asphalt Institute.

TABLE 5.—*Densities of bituminous mixtures compacted by various methods*

Track no.	Mixture identification	Bitumen in mixture		Percentage of voids in compacted mixture							
				Compacted in 6-inch cylindrical mold with 3-pound mallet		Compacted in roller molding machine		Circular track			
								After compacting with distributed traffic		After testing with concentrated traffic	
		By weight	By volume	Mixture voids	Aggregate voids	Mixture voids	Aggregate voids	Mixture voids	Aggregate voids	Mixture voids	Aggregate voids
		Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
1	A-3½	3.5	9.1	15.1	22.8	15.2	22.9	13.7	21.6	8.6	16.9
	B-3½	3.6	9.1	19.5	26.8	14.8	22.6	13.2	21.1	10.8	18.9
	C-3½	3.6	9.1	20.8	28.0	14.4	22.2	13.8	21.6	13.0	20.9
	D-3½	3.6	9.1	23.5	30.4	15.1	22.8	14.6	22.4	13.6	21.5
	E-3½ [1]	3.7	9.1	24.2	31.1	15.0	22.7	17.4	24.9	16.2	23.8
	Average				27.8		22.6		22.3		20.4
2	A-4	4.0	10.3	15.4	24.1	12.7	21.7	9.8	19.2	6.1	15.8
	B-4	4.1	10.3	18.7	27.1	12.1	21.2	10.2	19.5	6.5	16.1
	C-4	4.1	10.3	19.1	27.3	13.4	22.3	10.5	19.7	9.3	18.7
	D-4	4.1	10.3	20.7	28.9	13.4	22.3	10.3	19.6	9.8	19.2
	E-4 [1]	4.2	10.3	21.1	29.1	13.4	22.3	16.3	25.1	15.0	23.8
	Average				27.3		22.0		20.6		18.7
3	A-4½	4.5	11.5	13.7	23.7	8.2	18.8	5.2	16.1	2.3	13.5
	B-4½	4.6	11.5	15.9	25.6	9.8	20.2	7.0	17.7	3.4	14.5
	C-4½	4.6	11.5	18.3	27.8	10.7	21.0	8.6	19.1	2.9	14.1
	D-4½	4.7	11.5	19.9	29.2	11.4	21.6	11.3	21.5	4.6	15.6
	E-4½ [1]	4.7	11.5	23.2	32.0	10.6	20.9	14.7	24.5	10.3	20.6
	Average				27.7		20.5		19.8		15.7
4	A-5	5.0	12.7	10.2	21.5	5.5	17.3	1.3	13.9	1.2	13.7
	B-5	5.1	12.7	14.3	25.2	5.3	17.3	1.9	14.4	1.6	14.1
	C-5	5.1	12.7	17.0	27.5	7.5	19.2	5.1	17.2	3.0	15.3
	D-5	5.2	12.7	19.8	30.1	9.0	20.6	7.7	19.5	3.2	15.3
	E-5 [1]	5.3	12.7	20.7	30.8	9.4	21.0	13.0	24.1	11.0	22.3
	Average				27.0		19.1		17.8		16.1
5	A-5½	5.5	13.9	10.4	22.9	7.5	20.4	5.1	18.3	2.3	15.9
	B-5½	5.6	13.9	13.5	25.5	7.5	20.4	6.6	19.6	3.4	16.8
	C-5½	5.6	13.9	16.9	28.5	7.3	20.2	6.9	19.8	2.4	16.0
	D-5½	5.7	13.9	18.9	30.2	8.5	21.2	8.0	20.8	4.7	17.9
	E-5½ [1]	5.8	13.9	22.0	32.8	13.1	25.2	10.6	23.0	9.0	21.6
	Average				28.0		21.5		20.3		17.6
	Average of all mixtures				27.6		21.1		20.2		[2] 17.7

[1] All mixtures containing material E were compacted at approximately 150° F. All others were compacted at laboratory temperature.
[2] The voids content of the untreated dry aggregate compacted in a 4-inch cylindrical mold by vibrating 5 minutes with an electric hammer was 17.5 percent.

The data in table 5 are based on the following relations between mixture voids, aggregate voids, and aggregate and bitumen volumes. For the sake of brevity the following notations are used.

S = the total volume of a specimen of the compacted mixture.

A = the partial volume of the specimen occupied by the aggregate.

B = the partial volume of the specimen occupied by bitumen.

V = the volume of the voids or the partial volume of the specimen occupied by air.

$a=\frac{A}{S}\times 100$ = the percentage of aggregate in the compacted specimen, by volume.

$b=\frac{B}{S}\times 100$ = the percentage of bitumen in the compacted specimen, by volume.

$v_m=\frac{V}{S}\times 100$ = the percentage of air in the compacted specimen, by volume.

v_a = the percentage of aggregate voids, by volume, in the compacted specimen—space occupied by air and bituminous material.

Then $A+B+V=S$

and $\frac{A}{S}\times 100+\frac{B}{S}\times 100+\frac{V}{S}\times 100=\frac{S}{S}\times 100$ (1)

or $a+b+v_m=100$ (2)

also, $b+v_m=v_a$ (3)

In table 5 the percentage of bitumen by volume is expressed, not as a percentage of the volume of the compacted specimen, but as a percentage of the solid volume (aggregate plus bitumen), or $\frac{B}{A+B}\times 100$. This was done in order to show that the relation of the volume of bitumen to total solid volume was the same for all five sections in any individual track. This percentage, which is designated b', may be converted to an expression of the percentage of bitumen by volume of a particular specimen by multiplying it by the ratio of solid volume to total volume, $\frac{(100-v_m)}{100}$, in the specimen under consideration. Then equation (2) becomes

$$a+\frac{b'\ (100-v_m)}{100}+v_m=100 \quad (4)$$

and equation (3) becomes

$$\frac{b'\ (100-v_m)}{100}+v_m=v_a \quad (5)$$

As an example of the application of equation (5), the percentage of voids, v_m, for mixture A-3½, table 5, compacted in the 6-inch mold was 15.1 percent.

The percentage of bitumen by volume of solids was 9.1. Then from equation (5)

$$\frac{9.1\ (100-15.1)}{100}+15.1=v_a=22.8$$

as given in the table.

In table 5 the aggregate voids remaining after each method of compaction and after concentrated traffic are averaged for each bitumen content and grand averages are shown in each group for all five bitumen contents. Comparison of these average void contents indicates that of the three methods of compaction used, the cylinder method using a 3-pound mallet was least effective, rolling with distributed traffic was most effective, while the molding machine gave densities that were intermediate between those produced by the other two methods. The application of concentrated traffic on the track sections previously compacted under distributed traffic produced an appreciable amount of additional compaction in all of the sections, as indicated by their reduced void contents, and resulted in lower average void contents than were produced by any of the three methods of compaction used in these tests. The average void contents of the sections after testing under concentrated traffic were from 1.7 to 4.1 percent less than those of the same sections after compaction under distributed traffic; they were from 2.2 to 4.8 percent less than the average void contents of the specimens compacted in the roller molding machine; and they were from 7.4 to 12 percent less than the average void contents of the mallet-compacted specimens.

RELATIONSHIP FOUND TO EXIST BETWEEN STABILITY OF BITUMINOUS MORTAR AND STABILITY OF ENTIRE MIXTURE

Vibratory compaction tests on the dry aggregate gave a percentage of aggregate voids of 17.5, or 0.2 percent less than the average of the computed aggregate voids in all of the track sections after the concentrated traffic test. The least dense sample from the track after the concentrated traffic test, exclusive of mixtures containing the semisolid asphalt E, contained 21.5 percent aggregate voids and the most dense had 13.5 percent. It should be noted, therefore, that while the void content of the vibrated dry aggregate checked the average aggregate void content of the track specimens and was lower than that found by any other of the pre-compaction methods tried, it did not give the maximum obtainable compaction as evidenced by the lower aggregate void contents found in 14 of the track sections after the concentrated traffic test. Since the method used to obtain compaction by vibration is susceptible to considerable improvement, it is possible that the dry aggregate might be compacted to void contents comparable to those found in these 14 denser mixtures by an improved method.

Table 5 also shows that the concentrated traffic test, as well as all of the methods of compaction used, generally produced a considerably denser arrangement of the aggregate particles in the light oil mixtures than in those containing the more viscous materials. In the track sections after testing with concentrated traffic, as a typical example, the average computed aggregate voids ranged from 15.2 percent for the A mixtures to 22.4 percent for the E mixtures, or a variation of 7.2 percent resulting from differences in consistency of the bitumens.

The quantity of bitumen was also a factor in causing a marked variation in the density of the aggregates. In the track sections after testing with concentrated traffic, the 3½-percent mixtures averaged 20.4 percent aggregate voids. The percentage decreased progressively for increased bitumen contents to an average of 15.7 percent of aggregate voids for the 4½-percent mixtures and then rose progressively with increased bitumen to an average of 17.6 percent of aggregate voids for the mixtures containing 5½ percent of bitumen.

Hubbard-Field stability tests were made on the fine portion or mortar from a number of the circular track mixtures and also on a number of additional mortars having intermediate and lower bitumen contents. The materials for these tests were prepared separately by weighing the necessary amounts of crushed gravel and sand passing the no. 10 sieve and the same filler material as was used in the track mixtures. These ingredients, as well as the bitumen, were proportioned to produce mortars having the same grading as the mortars contained in the track mixtures and a slightly greater range of equivalent bitumen contents. The specimens were molded in standard Hubbard-Field molds under a pressure of 3,000 pounds per square inch maintained for 1 minute. They were allowed to cure in air for 24 hours and were then tested at laboratory temperature.

The results of the Hubbard-Field stability tests are shown in figure 8. These curves, together with those shown in figure 6, indicate that very definite relations exist between the stability of the fine portion or bituminous mortar and the stability of the entire mixture. The mixtures in the track showed loss of stability with increase in bitumen content as shown in figure 6, while the mortars showed a slightly upward trend in stability up to bitumen contents of 7 to 8 percent (approximately equivalent to 3½ and 4 percent in the track mixtures) and then a very rapid loss of stability for higher bitumen contents. However, with the exception of the D–4½ and D–5 mixtures, the range of equivalent bitumen contents through the zone of rapidly falling stabilities for the mortars corresponds closely to the range of bitumen contents in the track mixtures that showed lowered stability.

RESULTS OF TESTS ON THE EFFECT OF CONSISTENCY AND AMOUNT OF BITUMINOUS MATERIAL SUMMARIZED

The tests that have been described were made on only one type and grading of aggregate, and therefore the results should not be applied indiscriminately without further research involving other aggregates, and without proper allowance for special conditions to be met. However, it is believed that the results obtained will apply in the same relative way to materials and conditions other than those of the tests. For the combinations of materials studied and the conditions of these tests the following conclusions are indicated:

1. The addition of slow-curing, liquid bituminous material to aggregate of the coarse, dense-graded type reduces its stability or resistance to lateral flow under moving loads.
2. This effect is greatest for bituminous admixtures of low viscosity and tends to become progressively less as the consistency of the bituminous admixture is increased.
3. Loss of stability, as measured by rutting of the circular track under concentrated traffic, is small up to a certain critical bitumen content and increases rapidly as the percentage of bitumen is increased above the critical point.

4. Surfacing mixtures having very low bitumen contents, although possessing relatively high stability, fail to produce well-bonded wearing surfaces, and when the consistency of the bitumen is less than about 300 Saybolt-Furol viscosity at 122° F., the surface may ravel extensively under the direct action of traffic.

5. The use of bituminous materials having a viscosity of less than approximately 300 in surfacing mixtures with the type and grading of aggregate described necessitates extremely rigid control of the bitumen content. Material B, having a viscosity of 290, produced satisfactory results in only one proportion (4 percent). Mixture B–3½ raveled, and the mixtures containing 4½ percent or more of material B rutted and shoved excessively.

6. The use of more viscous liquid bituminous materials allows greater leeway in the permissible bitumen content of the mixture. The range of bitumen contents in satisfactory mixtures was from 3½ to 5 percent for the highly viscous material D and from 3½ to 4½ percent for material C.

EFFECT OF WATER ON THE STABILITY OF BITUMINOUS MIXTURES INVESTIGATED

Following the investigation of water-free mixtures, a series of tests was conducted to study the effect of water on the stability and service behavior of similar surfacing materials.

In the first four tests in this series, the surfaces were laid on the same sand-clay-gravel base as was used in the previous studies of water-free mixtures. The bearing power and uniformity of this base was excellent as long as it remained dry or only moderately damp. However, when the base was inundated in order to introduce capillary water into the surfacing mixture, the churning action of traffic caused marked local failures in the base. These failures took the form of widely spaced corrugations and contributed so seriously to the failure of the surfacing course that it was impossible to differentiate between surface failures resulting from weakness of the surfacing mixture and those caused by base failure.

Since these studies were primarily concerned with the qualities of the bituminous wearing coarse, the sand-clay-gravel base was discarded at the end of the fourth test of the series and a crushed-limestone base substituted. In constructing the limestone base the stone was thoroughly compacted and choked with clean sand. A bonded top was then formed by raking in dry portland cement, which was wetted by introducing water from below and allowed to set without puddling. There resulted a firm, well-bonded surface having sufficient porosity to allow free passage of water to the bituminous wearing course. No further trouble was encountered from base failures even when both base and surfacing course were inundated with water. Tracks 10, 11, and 12 were laid on this base.

Seven tracks were tested in this series—tracks 6 to 12, inclusive. Figures 9 to 13 show diagrammatically the layouts, test procedures, and notations on the behavior of the test sections for tracks 6 to 10.

Although a few of the wettest surfaces rutted considerably, other more characteristic types of failure were observed on many of the wet sections. Such evidences of failure were corrugations, surface cracking, and surface peeling followed by rapid pot holing or local raveling.

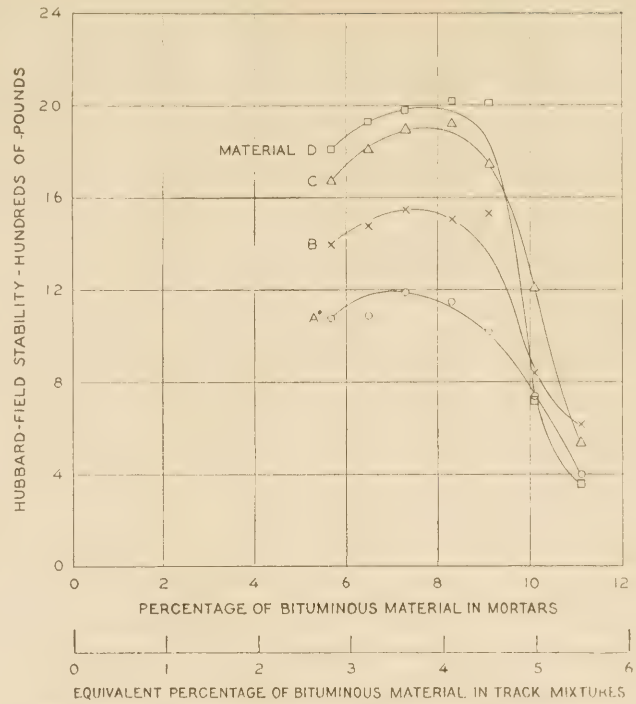
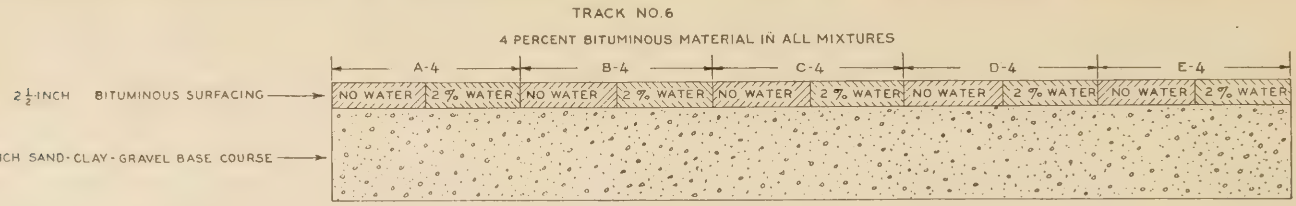


FIGURE 8.—RELATIONS BETWEEN BITUMEN CONTENT AND HUBBARD-FIELD STABILITY OF MORTARS MADE BY ADDING BITUMINOUS MATERIAL TO THE FINE PORTION OF THE CIRCULAR TRACK AGGREGATE.

As shown in figure 9, track 6 was laid in five sections, each section containing 4 percent of bitumen and each having one of the five grades of bitumen used in the previous investigation of water-free mixtures. Each section was further subdivided into two subsections, one being laid without water in the mixture and one having 2 percent of water added to the aggregate before the bitumen was applied. After compaction of the surfacing mixtures on the dry base, water was admitted to the base and the water level maintained at 9 inches below the track surface during the first 50,000 wheel trips of concentrated traffic and at 4½ inches below the surface during the last 25,000 wheel trips.

Comparison of the observed behavior of the test sections in this track clearly indicated the superiority of the mixtures containing the highly viscous to semisolid bituminous materials over the mixtures containing lighter materials in resisting the detrimental effects of water.

Although, as previously mentioned, it was difficult to distinguish between failures resulting from surface weakness and those caused by base settlement, it was observed that the sections having low viscosity bitumen in the surfacing mixtures failed earlier and to a greater extent than did those having the highly viscous to semisolid bituminous materials. Figure 9 shows the relation of time of occurrence and observed extent of failure to the amount of traffic applied. The surface on section A, where the lightest bitumen was used, raveled during and immediately following compaction and, in the early stages of the test, developed considerable corrugation. After 50,000 wheel trips of concentrated traffic, it was badly rutted in the originally dry half and somewhat less badly rutted in the half laid with 2 percent of water. Part of this rutting was undoubtedly caused by base failure, but, regardless of whether or not this was the



CONDITIONS OF THE TEST — BEHAVIOR OF TEST SECTIONS

OPERATION	BASE CONDITION	TIME	NUMBER OF WHEEL TRIPS										
COMPACTING (DISTRIBUTED TRAFFIC)	DRY	4 DAYS	0 4,500	RAVELED BADLY	RAVELED SOMEWHAT	REMAINED IN GOOD CONDITION							
TESTING (CONCENTRATED TRAFFIC)	WATER 9 INCHES BELOW SURFACE	9 DAYS	0										
			5,000	LESS RAVELING	SLIGHT RAVELING	CRACKING							
			12,000	CORRUGATING		CORRUGATING							
			50,000	BADLY RUTTED	RUTTED	RUTTED AND CRACKED	RUTTED	SLIGHTLY RUTTED & CRACKED	SLIGHTLY RUTTED	SLIGHTLY RUTTED & CRACKED	SLIGHTLY RUTTED	SLIGHT CRACKING	
TESTING (CONCENTRATED TRAFFIC)	WATER 4½ INCHES BELOW SURFACE	6 DAYS	75,000	BASE IN ALL SECTIONS SETTLED IRREGULARLY SOON AFTER WATER LEVEL WAS RAISED. THIS CAUSED GENERAL CRACKING IN ALL SECTIONS OF SURFACING BUT NO SECTION EXCEPT E SHOWED SUPERIORITY OVER THE OTHERS.									

FIGURE 9.—EFFECT OF WATER ON THE BEHAVIOR OF MIXTURES CONTAINING 4 PERCENT OF THE VARIOUS BITUMINOUS MATERIALS.

case, the condition of section A after the 50,000 wheel trips was clearly worse than that of any other section with the possible exception of section B in which the next heavier grade of bitumen was used.

While showing no noticeable raveling, section B developed cracks in the originally dry half and corrugations in both halves early in the test and rutted somewhat less than did section A during the 50,000 wheel trips before the water level was raised in the base.

Sections C and D, in which the two next heavier grades of bitumen were used, showed no evidence of failure until after 12,000 wheel trips of concentrated traffic had been applied, and from then until the completion of 50,000 wheel trips developed only slight cracks in the originally dry sections and a moderate amount of rutting throughout.

Section E, which contained the semisolid bituminous material, showed no evidence of failure except slight cracking in the originally dry half up to 50,000 wheel trips.

Since quantitative measurement of the rutting in track 6 was impractical because of the longitudinal irregularity of the ruts, comparison cannot be made between the performance of this track and track 2 in which the 4-percent, water-free mixtures were tested (see table 4). However, it was observed that the principal difference between these two tracks was a greater tendency on the part of track 6 to corrugate in the sections having bitumen of low viscosity, and a tendency for all sections to develop cracking. This cracking, as well as a general rutting and increased roughness, became extremely noticeable on all sections of track 6 after the water level was raised to within 4½ inches of the top of the curbs at 50,000 wheel trips. During the ensuing 25,000 wheel trips the ruts and corrugations developed rapidly in all the sections. In some places the additional displacement amounted to one-half inch or more without, however, materially changing the thickness of the surface course in the bottoms of the ruts. In other words, the additional and comparatively rapid rutting and corrugating were largely the result of base failure caused by the higher water level.

WET MIXTURES ON DRY BASES TEND TO DRY OUT AND REGAIN STABILITY

Tracks 7 and 8, data for which are shown in figures 10 and 11, were identical as to grade and quantity of bitumen and base conditions. Both contained 4 percent of material C in all sections and were laid and tested on a dry base. Both tracks were divided into five sections that varied only in the amount of water added to the aggregates before mixing with bitumen. One section in each was surfaced with a mixture prepared with air-dried aggregate containing about 0.4 percent of water but to which no water had been added. In the remaining four sections of each track, the respective mixtures were prepared from aggregates to which 2, 3, 4, and 6 percent of water had been added.

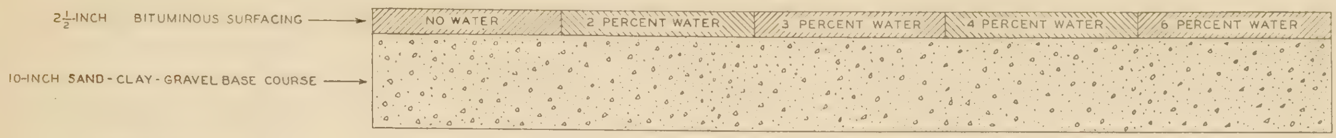
The wet sections in track 7 after compaction contained considerably less water than the amount which had been added to the aggregates. In fact, only two of them contained over 2 percent of moisture when the traffic test was started. Of these two, the section containing 2.8 percent of residual moisture developed some alligator cracks under traffic, and the section containing 5 percent of water rutted appreciably, indicating considerable loss of stability, and it also developed alligator cracks.

The section that was laid dry and the two wet sections in which the moisture content had fallen to 2 percent or less during laying and compacting showed no evidence of failure at the end of the test. The test on track 7 was concluded at 15,000 wheel trips.

Track 8 was identical with track 7 except that mixing and laying operations were speeded up somewhat to reduce the loss of water from the wet mixtures. Only 1,000 wheel trips of compacting traffic were applied so that compaction was completed and test traffic started within 4 hours after the surfacing material was laid. During both compacting and early testing the surfaces of all the sections were lightly sprinkled at intervals to retard the loss of moisture by evaporation. The actual moisture contents of the sections containing 2 percent and 3 percent of water were reasonably close to the designed contents, but the sections originally containing 4 percent and 6 percent of water actually contained only 3.4 and 4.4 percent, respectively, when testing was started. Rutting occurred only in the wettest section, as was the case in track 7. The rutting in the section originally containing 6 percent of water began as soon as concentrated traffic was started and had virtually reached its maximum at 1,000 wheel trips. After the sprinkling was discontinued (at 10,000 wheel trips of test traffic)

TRACK NO. 7

4 PERCENT OF MATERIAL C IN ALL MIXTURES



CONDITIONS OF THE TEST — BEHAVIOR OF TEST SECTIONS

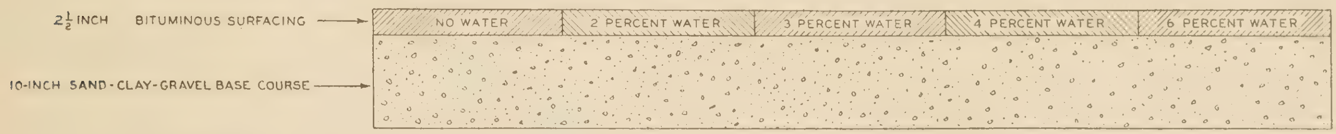
OPERATION	BASE CONDITION	TIME	NUMBER OF WHEEL TRIPS					
COMPACTING (DISTRIBUTED TRAFFIC)	DRY	4 DAYS	0					
			3,500	GOOD CONDITION WATER 0.4 PERCENT [1]	GOOD CONDITION WATER 1.3 PERCENT [1]	GOOD CONDITION WATER 2.0 PERCENT [1]	CRACKED EXTENSIVELY WATER 2.8 PERCENT [1]	CRACKED EXTENSIVELY WATER 5.0 PERCENT [1]
TESTING (CONCENTRATED TRAFFIC)	DRY	5 DAYS	0					
			100					RUTTING
			5,000					WATER 2.6 PERCENT
			15,000	NO EVIDENCE OF FAILURE WATER 0.4 PERCENT	NO EVIDENCE OF FAILURE WATER 1.1 PERCENT	NO EVIDENCE OF FAILURE WATER 1.6 PERCENT	EXTENSIVE CRACKS WATER 1.9 PERCENT	EXTENSIVE CRACKS NO ADDITIONAL RUTTING WATER 2.6 PERCENT

[1] WATER CONTENT DETERMINED ON LOOSE MATERIAL BEFORE APPLYING TRAFFIC.

FIGURE 10.—EFFECT OF VARIOUS AMOUNTS OF WATER ON THE BEHAVIOR OF MIXTURES CONTAINING 4 PERCENT OF MATERIAL C.

TRACK NO. 8

4 PERCENT OF MATERIAL C IN ALL MIXTURES



CONDITIONS OF THE TEST — BEHAVIOR OF TEST SECTIONS

OPERATION	BASE CONDITION	TIME	NUMBER OF WHEEL TRIPS					
COMPACTING (DISTRIBUTED TRAFFIC)	DRY	4 HOURS	0	LIGHT SPRINKLING STARTED				
			1,000	WATER 0.2 PERCENT [1]	WATER 2:3 PERCENT [1]	WATER 3.0 PERCENT [1]	WATER 3.4 PERCENT [1]	WATER 4.4 PERCENT [1]
TESTING (CONCENTRATED TRAFFIC)	DRY	4 HOURS	0					RUTTING STARTED IMMEDIATELY
			2,000	NO EVIDENCE OF FAILURE				WATER 2.3% VERY LITTLE RUTTING; WATER 3.2% RUTTED BADLY
		3 DAYS	10,000	SRRINKLING DISCONTINUED				NO FURTHER RUTTING; RUT REPAIRED
			15,000	LONGITUDINAL CRACKS				ROUGH BUT NO FURTHER RUTTING
		6 DAYS	29,000	WATER 0.3 PERCENT	WATER 1.0 PERCENT	WATER 1.6 PERCENT	WATER 1.4 PERCENT	WATER 1.9 PERCENT, ROUGHER BUT NO FURTHER RUTTING
			44,000	NO FURTHER FAILURE	NO EVIDENCE OF FAILURE	SLIGHT SCALING	SLIGHT SCALING	WATER 1.3 PERCENT, SCALING, NO ADDITIONAL ROUGHNESS

[1] WATER CONTENT DETERMINED AT START OF COMPACTION PERIOD.

FIGURE 11.—EFFECT OF VARIOUS AMOUNTS OF WATER ON THE BEHAVIOR OF MIXTURES CONTAINING 4 PERCENT OF MATERIAL C. THE SECTIONS WERE SPRINKLED TO RETARD LOSS OF MOISTURE BY EVAPORATION.

the mixtures lost moisture so rapidly that at 29,000 wheel trips of test traffic none of them contained as much as 2 percent of water. At 44,000 wheel trips of test traffic, when the test was discontinued, the sections originally having 3, 4, and 6 percent of water showed a slight tendency to scale or peel, and the dry section had developed some longitudinal surface cracks, due probably to the light sprinkling. No indication of failure was evident in the section that originally contained 2 percent of water.

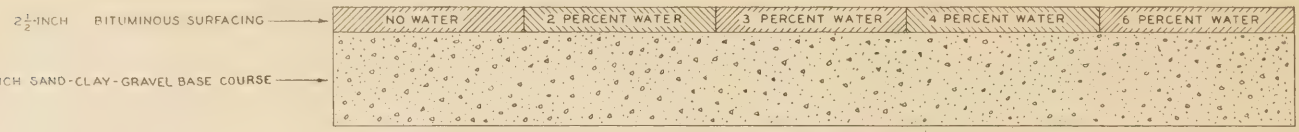
Track 9 (see fig. 12) was similar to tracks 7 and 8 except that 4½ percent of material C was used in the mixtures instead of 4 percent. Mixing and laying operations were further hastened to avoid, as much as possible, loss of moisture from the mixtures. The number of trips for compaction was reduced to 300, and compaction was finished and testing started within 2 hours after the mixtures were laid. This track was not sprinkled.

The compacted mixtures had water contents from 0.3 percent to 1 percent below the original water contents. Again, the only wet section showing reduced stability by rutting was that laid with 6 percent of water and containing 5 percent when testing with concentrated traffic was started. Rutting and corrugation developed so rapidly in this section that it had to be replaced at 1,000 wheel trips of test traffic with a more stable material in order to continue the test on the other sections. The highest moisture content in any of the other sections when testing was started was 3.1 percent. The dry section showed very slight rutting, the amount corresponding closely to that recorded for the same mixture in the tests on water-free mixtures. The failure of the wet sections containing from 1.7 percent to 3.1 percent of water to rut at all, whereas the dry section showed a normal amount of rutting, is attributed to a peculiarity of such mixtures which was observed throughout this series of test, namely, that the addition of a small amount of water (generally less than 3 percent) appeared to make the mixture harsh and hard to compact.

Low stability is a characteristic of oily, easily compacted mixtures or of mixtures that have been compacted to such an extent that virtually all their void spaces are filled with liquid. It follows, therefore, that if a small amount of water causes harshness in the mixture and thereby retards compaction, the mixtures, although having low stability when thoroughly compacted, may show a temporary stability somewhat higher than normal during the comparatively long period of traffic application necessary to bring them to their ultimate density.

TRACK NO. 9

4½ PERCENT OF MATERIAL C IN ALL MIXTURES



CONDITIONS OF THE TEST				BEHAVIOR OF TEST SECTIONS				
OPERATION	BASE CONDITION	TIME	NUMBER OF WHEEL TRIPS					
COMPACTING (DISTRIBUTED TRAFFIC)	DRY	2 HOURS	0 300	GOOD CONDITION. WATER 0.2 PERCENT 1/	GOOD CONDITION. WATER 1.7 PERCENT 1/	GOOD CONDITION. WATER 2.3 PERCENT 1/	GOOD CONDITION. WATER 3.1 PERCENT 1/	MOVED NOTICEABLY UNDER WHEELS. WATER 5.0 PERCENT 1/
TESTING (CONCENTRATED TRAFFIC)	DRY	1½ DAYS	0					RUTTING IMMEDIATELY AND LONGITUDINAL CRACKS
			1,000					WATER 4 PERCENT. BADLY RUTTED. DISCONTINUED
			2,100	WATER 0.2 PERCENT	WATER 1.4 PERCENT	WATER 1.6 PERCENT	WATER 2.7 PERCENT	
			5,000	SOME RUTTING				
			7,800	RUTTED ¼ INCH 2/	NO RUTTING	NO RUTTING	NO RUTTING	

1/ WATER CONTENT DETERMINED ON LOOSE MATERIAL BEFORE APPLYING TRAFFIC.
2/ MAXIMUM DEPTH OF RUT AT ANY POINT.

FIGURE 12.—EFFECT OF VARIOUS AMOUNTS OF WATER ON THE BEHAVIOR OF MIXTURES CONTAINING 4½ PERCENT OF MATERIAL C.

MIXTURES WITH HIGH BITUMEN CONTENTS ABSORBED LEAST WATER FROM BASE COURSE

Track 10 (see fig. 13) consisted of five sections, all containing material C but in amounts varying by increments of one-half percent from 3½ to 5½ percent of bitumen. The mixtures were laid without the addition of water and the base was kept dry during compaction of the surfacing mixtures. After the sections were compacted by 3,000 wheel trips, 4,000 additional wheel trips of distributed traffic were applied with the base flooded to within one-fourth inch of the bottom of the bituminous mat.

None of the sections showed any indication of failure except that the sections containing 5 and 5½ percent of bitumen showed a normal low stability resulting from their high bitumen contents. The water was then raised to within 1½ inches of the top of the bituminous mat and 1,700 additional wheel trips were applied, making a total of 5,700 wheel trips of distributed traffic. The mixtures were then tested for water content. The results of these tests are shown in figure 13 opposite the first entry of 5,700 wheel trips.

At that time the sections containing 3½, 4, and 4½ percent of bitumen were still in good condition, but the section containing 5 percent was badly cracked and the section containing 5½ percent was rubbery and unstable. The water level was again raised, this time to within one-fourth inch of the top of the bituminous mat, and maintained there without additional traffic for 18 hours or three-fourths of a day. The sections were again tested for water content and the results are shown in figure 13 opposite the second entry of 5,700 wheel trips. All of these tests of water content were made only on the top inch of the mixtures.

The first test of water content indicated that capillarity and the action of traffic had caused some water to rise above the free water level into the top half of the bituminous mixtures. As shown in figure 13, the amounts ranged from 0.5 percent for the mixture containing 3½ percent of bitumen to 2.1 percent for the mixture with 4½ percent of bitumen, and then downward to 0.7 percent for the mixture with 5½ percent of bitumen.

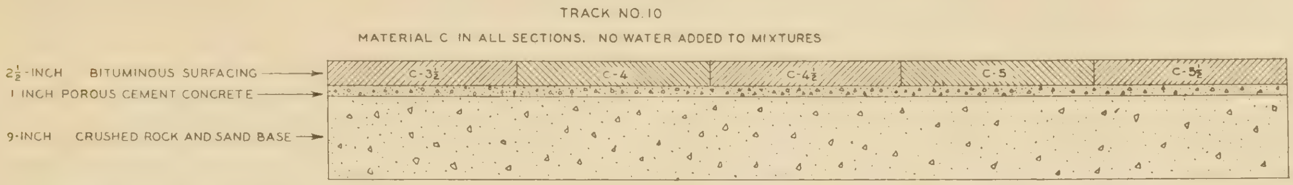
During the 18 hours when the water level was within one-fourth inch of the top of the bituminous mat and no traffic was being applied, upward percolation caused the water content in the top inch of the mixtures having 3½ and 4 percent of bitumen to increase to 2 percent and 1.5 percent, respectively. No increase in water content occurred in the top inch of the other three sections having 4½, 5, and 5½ percent of bitumen. On the contrary there was a very slight decrease, which probably was the result of the inability of the water to percolate upward through these richer and, by then, well-compacted mixtures fast enough to offset the losses by surface evaporation.

The water level was next lowered to 1½ inches below the top of the mat and maintained at this level during the application of 3,300 additional wheel trips of distributed traffic. This brought the total of all distributed test traffic on this track up to 9,000 wheel trips. At 9,000 wheel trips the water content was determined both at the top and bottom of each section. The results are shown in figure 13.

In the top inch, the mixtures having 3½ and 4 percent of bitumen showed additional gains in water content of 0.6 and 0.4 percent, respectively. The mixture with 4½ percent of bitumen showed no change in water content and those with 5 and 5½ percent of bitumen showed additional losses of 0.1 and 0.3 percent, respectively. The bottom inch of each section contained a considerably higher percentage of water than did the top inch. In both the top and bottom inch, comparing the various sections, the water content decreased progressively with higher bitumen contents. At this time the sections containing 3½, 4, and 4½ percent of bitumen were in good condition and those containing 5 and 5½ percent of bitumen both showed alligator cracking and were wavy and highly plastic.

In the final phase of the test, the water level was lowered to the bottom of the bituminous mat and concentrated traffic was applied. The mixtures having 5 and 5½ percent of bitumen failed immediately under this type of traffic and after 500 wheel trips were replaced with other material to allow completion of the test on the remaining sections.

It is of interest in connection with the failure of these two sections that when they began to rut, the surface cracks opened up and after about 200 wheel trips a considerable quantity of mud was ejected through them. This mud, although appearing from its color and texture to contain no bitumen, proved upon analysis to contain 8.9 percent of bitumen on the basis of its water-free weight. Its water content was 25 percent. The bitumen in this ejected material had



CONDITIONS OF THE TEST				BEHAVIOR OF TEST SECTIONS				
OPERATION	BASE CONDITION	TIME	NUMBER OF WHEEL TRIPS	C-3½	C-4	C-4½	C-5	C-5½
COMPACTING (DISTRIBUTED TRAFFIC)	DRY	2½ DAYS	0					
			3,000					
TESTING (DISTRIBUTED TRAFFIC)	WET. WATER ¼ INCH BELOW BITUMINOUS COURSE	3 DAYS	0				GOOD CONDITION	GOOD CONDITION
			4,000	GOOD CONDITION	GOOD CONDITION	GOOD CONDITION	MOVED SLIGHTLY UNDER WHEELS	MOVED CONSIDERABLY UNDER WHEELS
	WET. WATER 1½ INCH BELOW TOP OF BITUMINOUS COURSE	3 DAYS	5,700 [1]	WATER, TOP, 0.5 PERCENT	WATER, TOP, 0.6 PERCENT	WATER, TOP, 2.1 PERCENT	CRACKED EXTENSIVELY WATER, TOP, 1.1 PERCENT	RUBBERY, UNSTABLE WATER, TOP, 0.7 PERCENT
			5,700 [1]	WATER, TOP, 2.0 PERCENT	WATER, TOP, 1.5 PERCENT	WATER, TOP, 1.8 PERCENT	WATER, TOP, 0.9 PERCENT	WATER, TOP, 0.6 PERCENT
			9,000	PEELING AND PITTING WATER, TOP, 2.6 PERCENT BOTTOM, 5.3 PERCENT	PEELING AND PITTING WATER, TOP, 1.9 PERCENT BOTTOM, 3.9 PERCENT	SLIGHT PEELING & PITTING WATER, TOP, 1.8 PERCENT BOTTOM, 3.0 PERCENT	CRACKED EXTENSIVELY WAVY, UNSTABLE WATER, TOP, 0.8 PERCENT BOTTOM, 2.4 PERCENT	CRACKED EXTENSIVELY WAVY, UNSTABLE WATER, TOP, 0.3 PERCENT BOTTOM, 2.1 PERCENT
TESTING (CONCENTRATED TRAFFIC)	WET. WATER IN CONTACT WITH BOTTOM OF BITUMINOUS COURSE	5 DAYS	0				RUTTED IMMEDIATELY	
			200				MUD EJECTED THROUGH CRACKS [2]	MUD EJECTED THROUGH CRACKS AND AT CURB [2]
			500	CRACKS BEGINNING TO DEVELOP			DISCONTINUED	DISCONTINUED
			1,500		CRACKED EXTENSIVELY	CRACKED EXTENSIVELY		
			3,700	CRACKED EXTENSIVELY	MUD EJECTED [2]			
			6,800	MUD EJECTED [2]				
			8,000			MUD EJECTED [2]		
			8,000	TEST STOPPED. SECTIONS BADLY POT-HOLED AND RAVELED				

1/ AT 5,700 TRIPS WATER CONTENT TESTED AND WATER LEVEL RAISED TO ¼ INCH OF TOP OF BITUMINOUS COURSE AND ALLOWED TO STAND 18 HOURS. WATER CONTENT AGAIN TESTED AND SHOWED THE CHANGES INDICATED. WATER LEVEL THEN RETURNED TO 1½ INCHES BELOW TOP OF BITUMINOUS COURSE.

2/ THIS MUD CONTAINED 25 PERCENT WATER AND OF THE WATER-FREE MATERIAL 8.9 PERCENT WAS BITUMINOUS MATERIAL.

FIGURE 13.—EFFECT OF WATER AND BITUMEN CONTENT ON THE BEHAVIOR OF MIXTURES CONTAINING VARIOUS PERCENTAGES OF MATERIAL C.

apparently been completely emulsified by the action of traffic on the water-soaked surfacing mixture.

Figure 14, which shows the section containing 5 percent of material C after 500 wheel trips of concentrated traffic, illustrates the condition of this section and the section containing 5½ percent of material C when they were discarded.

The sections with 3½, 4, and 4½ percent of bitumen developed surface cracks at 500 wheel trips and some mud was ejected through the cracks in all three sections before the conclusion of the test. The section having 4½ percent of bitumen was the last of the five to eject the mud and oil emulsion and was apparently least affected by the action of moisture. The test was concluded at 8,000 wheel trips.

The water conditions for track 10 were purposely made extremely severe in order to accelerate the test and to show, as clearly as possible, the comparative differences in behavior of the sections. The tests indicated that the susceptibility of these mixtures to damage from excessive moisture increased as their bitumen contents were increased above 4½ percent. This is evidenced both by the shorter time required to produce failure of the rich sections compared with the lean ones, and by the greater extent of the failure in the rich sections for a given amount of traffic.

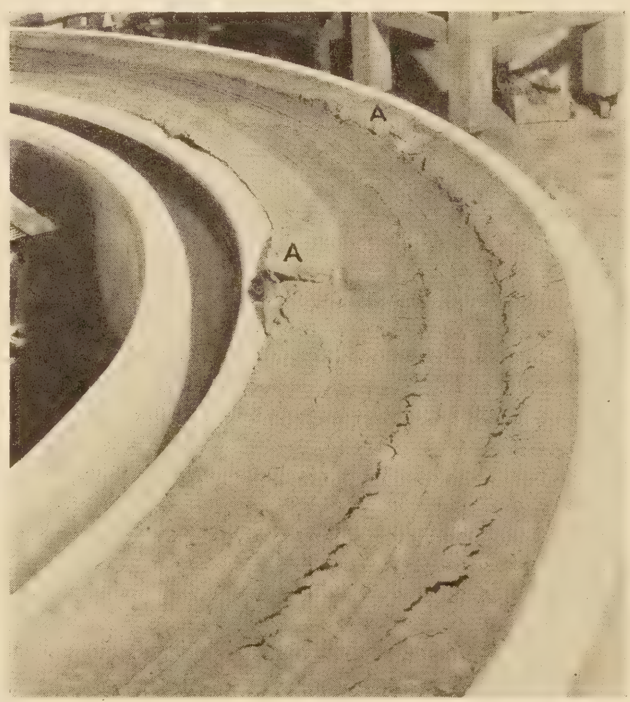


FIGURE 14.—SECTION OF TRACK NO. 10 CONTAINING 5 PERCENT OF MATERIAL C, AFTER 9,000 WHEEL TRIPS OF DISTRIBUTED TRAFFIC AND 500 WHEEL TRIPS OF CONCENTRATED TRAFFIC. MUD WAS EJECTED FROM THE SPOTS MARKED "A".

ADDING WATER TO AGGREGATE FOUND LESS DETRIMENTAL THAN ADDING WATER TO OILED MIXTURE

Comparison of the results of the tests on track 10 with those on tracks 7, 8, and 9, in which water was contained in the mixtures but not in the base, indicates that water in the base structure is a more serious cause of failure than moisture in the surfacing mixtures when the base is dry. This is due to the fact that a wet base tends to maintain the surfacing mixture in a wet, unstable, and generally weakened condition for as long a time as drainage conditions remain unsatisfactory; whereas, if the base is well drained and dry, a wet mixture placed on top of it will, under favorable weather conditions, dry out and become stable in a comparatively short time. It should be noted, however, that in several instances test mixtures which contained more than 2½ to 3 percent of moisture when the test traffic was started, even when the base course was dry, developed alligator cracks which failed to heal after the mixtures had partially dried. It was observed that cracks, once formed, persisted until the surface was broken up and remixed.

Tracks 11 and 12 were designed to show the effect of (*a*) water contained in the aggregate at the time of applying the bitumen, and (*b*) water incorporated in the mixture after oiling but before compacting. Each of these two tracks was divided into six sections, three of which were surfaced with mixtures containing 4½ percent of material B and the other three with mixtures containing 4½ percent of material D. In track 11 water was added to the aggregate 24 hours before applying the bitumen, and in track 12 water was added and mixed into the oiled aggregate 24 hours before the track was laid and compacted. In both tracks the percentages of water used were, on the basis of the weight of the dry aggregate, 2, 4, and 6 percent for the B and also for the D bituminous mixtures.

These two tracks were each given only 300 wheel trips of distributed traffic for compaction, due to the extremely low stability of the mixtures with material B containing 6 percent of water. Further compaction of these mixtures would have resulted in pushing a large part of the material out of the track and over the curb. Two of the mixtures containing material B, that having 6 percent of water added to the aggregate (track 11) and that having 6 percent of water added to the mixture (track 12), failed completely within the first 600 wheel trips of concentrated traffic and had to be replaced with more stable material before the tests could be continued on the other sections. All but two of the sections showed average vertical displacements in excess of 0.1 inch at 5,000 wheel trips, which would cause them to be classified as unsatisfactory according to the procedure followed in the classification of the water-free mixtures previously discussed in this report. The two exceptions were the mixtures with material D containing 2 and 4 percent water added to the aggregates.

The average vertical displacements at 5,000 wheel trips for the mixtures in tracks 11 and 12 are given in table 6. Comparison of these data with the data given in table 4 for the water-free mixtures clearly shows the effect of water in lowering the stability of these bituminous mixtures.

TABLE 6.—*Average vertical displacement of bituminous mixtures after 5,000 wheel trips*

[Tracks 11 and 12; 4½ percent of bitumen in all sections]

Track no.	Material	Water		Average vertical displacement at 5,000 wheels trips
		Percent	Added to—	
				Inches
11	B	2	Aggregate	0.29
11	B	4	do	.29
11	B	6	do	(1)
12	B	2	Oiled mixture	.32
12	B	4	do	[2] 1.92
12	B	6	do	(1)
11	D	2	Aggregate	.10
11	D	4	do	.10
11	D	6	do	[2] 1.02
12	D	2	Oiled mixture	.17
12	D	4	do	.50
12	D	6	do	.58

[1] Failed completely within 600 wheel trips.
[2] Extrapolated by extending displacement curve.

The test results indicated that, in general, a greater loss of stability took place in the mixtures in which water was added to the oiled aggregate than in those in which the water was added to the aggregate before the bitumen was applied. The results also corroborated the other test data which pointed to a definite superiority of the more viscous materials over those of low viscosity in resisting the effect of water.

In considering the results of the tests on wet mixtures it should be pointed out that the mineral filler used in these mixtures, while not an ideal filler material, was considerably better in quality than much of the soil that has often been used as filler in low-cost road surfaces. It is believed that had a clay filler containing more colloidal material been used, the detrimental effect of water on the mixtures tested would have been more striking.

TEST RESULTS ON WET MIXTURES SUMMARIZED

1. Although water in the mixtures caused cracking in the lean sections as well as in the rich ones, the lean mixtures showed very little loss of stability due to the addition of water while the richer mixtures showed a marked loss of stability from this cause.
2. Both dry and wet mixtures tested on wet bases lost stability more rapidly and were ultimately much less stable when the bitumen content was high than when it was low.
3. The rich mixtures did not absorb as much water from the wet bases as did the lean ones but this did not prevent their loss of stability since less additional liquid was required to affect them.
4. The mixtures containing bitumens of low viscosity lost stability more rapidly and to a greater degree, due to the action of water, than did those containing the heavier materials.
5. Cracking, pitting, and corrugating comprised the typical failures on the wet sections, and in addition, rutting occurred in the wet sections containing the higher percentages of bituminous material.
6. Surfaces that cracked while wet failed to heal after drying. The cracks persisted until the surfacing mixtures were broken up, remixed, and relaid.
7. Loss of stability occurred both in the wet mixtures on dry bases and in the mixtures that were tested on wet bases. However, while the former tended to dry out rapidly and regain their stability, the condition of the latter continued to grow steadily worse with the application of additional traffic.
8. Water added to the oiled aggregate mixtures caused, in general, a somewhat greater loss of stability than did water added to the aggregate before oiling. The reverse, however, was true of the wettest mixtures (those containing 6 percent of water).
9. The tests appear to justify the provision in numerous present-day specifications that limits the amount of moisture permitted in oil-processed surfacing mixtures to 2 percent at the time of laying. Such a provision seems desirable in order to insure against surface cracks which, once formed, fail to heal even after the moisture in the surface has evaporated.

INDEXES OF HIGHWAY CONSTRUCTION COSTS

REPORTED BY THE DIVISION OF MANAGEMENT, BUREAU OF PUBLIC ROADS

THE purchasing power of funds expended for highway construction, when expressed in miles of highway annually placed under construction, shows variations from year to year because of (1) actual variations in the cost of materials and labor entering into such construction, and (2) changes in design features, types, and quantities of materials actually used.

The effect of lowered prices of constituent units is immediately reflected in a downward trend in costs per mile whenever the quantities of materials used and labor required are subject to only minor variations. However, changing traffic conditions have required wider surfaces, longer sight distances, flatter curves, and other features conducive to safety with increased speed. Consequently, the effects of lower unit prices during recent years have been largely offset by the increased quantities of materials and excavation actually used, and average costs per mile have not fluctuated in accordance with fluctuations in the unit price of materials.

As a normal consequence of constantly increasing traffic on our highways, highway construction is continually undergoing changes, both in design and in materials used, and these changes have tended to complicate the development of simple index figures. To meet this condition three sets of index figures have been prepared.

1. A price trend index, based on the varying unit costs of a composite mile composed of the same quantities and materials for each year.

2. A usage trend index that shows the variations in quantities of excavation, surfacing, and structures actually placed in the composite mile constructed each year.

3. A cost trend index, that is based on the actual cost of the composite mile constructed each year.

Data for the Federal fiscal years 1925 to 1929 were taken as a basis for the calculations. The variations in price trend for the years 1922 to 1935 for the major components as well as for the composite mile are shown in figure 1.

Price, cost, and usage trend indexes are shown in figure 2 for the period 1923 to 1934. The effects of price and usage are combined to produce a cost trend for the composite mile. The cost trend follows a more uniform course than does either the usage or the price trend.

COST TREND OBTAINED BY COMBINING PRICE TREND AND USAGE TREND FOR COMPOSITE MILE OF HIGHWAY

The data covering materials, quantities, and unit costs were collected by the Bureau of Public Roads from the prices shown in the contracts awarded for road construction financed in whole or in part from Federal funds allotted to the States for construction on the Federal-aid highway system. Samples were taken from work financed wholly with State funds and it was found that Federal-aid and State projects were built to about the same standard.

FIGURE 1.—PRICE TREND IN HIGHWAY CONSTRUCTION. AVERAGES FOR 1925 TO 1929 TAKEN AS A BASE.

Careful consideration of the available data led to the conclusion that a satisfactory usage index could be obtained if a composite mile of surfacing representative of the types of construction in Federal-aid and State annual programs were used. Accordingly, the component types of surfacing entering into the composite mile were taken from records of the combined highway mileages built annually, and the correlated items (grading, structural concrete, and steel) were based on the records available from construction with Federal funds. The propriety of the above procedure is assured by the fact that governing specifications are the same for both Federal-aid and wholly State construction, and that design and supervision of construction are performed by the State highway departments.

In building highways throughout the country the engineer must take into account wide differences in soils, availability and quality of materials, temperature, rainfall, traffic, and other factors, with a resulting wide range in construction practice. Many materials are important locally, but are of little significance to the country as a whole. Therefore, in the interest of simplifying reduction of data the following general items were selected as a basis for the indexes.

From Bureau of Public Roads records of bid prices:

Excavation—

- Common.
- Unclassified.
- Rock.

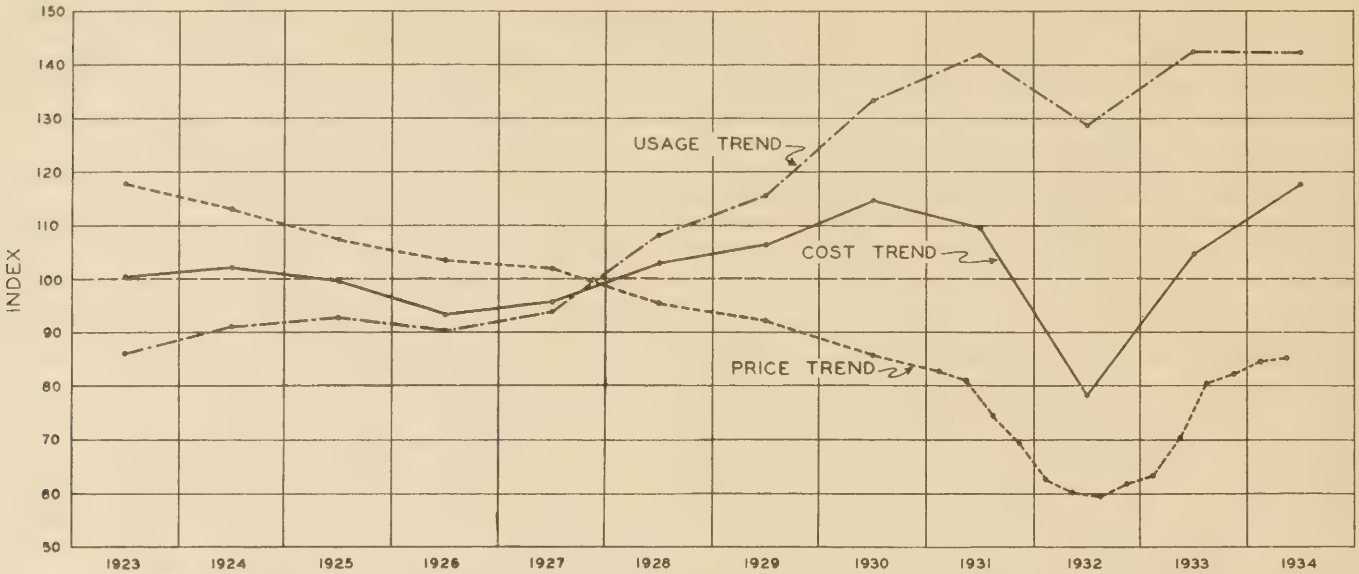


FIGURE 2.—INDEXES OF HIGHWAY CONSTRUCTION COST. AVERAGES FOR 1925 TO 1929 TAKEN AS A BASE. PRICE INDEX SHOWS TREND IN COST OF COMPOSITE MILE COMPOSED OF SAME QUANTITIES OF EXCAVATION, SURFACING, AND STRUCTURES IN EACH YEAR. USAGE INDEX SHOWS TREND IN QUANTITIES OF EXCAVATION, SURFACING, AND STRUCTURES USED PER MILE IN EACH YEAR. COST INDEX, TAKING ACCOUNT OF USAGE, SHOWS TREND IN ACTUAL COST PER MILE.

Structures—
- Reinforcing steel.
- Structural steel.
- Structural concrete, class A.
- Structural concrete, class B.
- Structural concrete, class C.

From records of mileage of State highways constructed:
- Gravel and sand-clay.
- Macadam.
- Bituminous macadam.
- Bituminous concrete.
- Portland-cement concrete.
- Brick.

These items cover somewhat more than 90 percent of the total cost of highway construction. Therefore, though their number is not great, they appear to be adequate. The items not used involve about the same basic commodities, manufacturing processes, transportation problems, and the same classes of labor that were involved in the items used. To include them would complicate the calculations but probably would neither clarify nor improve the result.

These representative items were accumulated and weighted, and further consolidated into three general groups—excavation, surfacing, and structures. The general group of excavation includes the three types of excavation, common, rock, and unclassified, and in addition includes the low-type surfaces such as topsoil, sand-clay, gravel, and treated and untreated macadam. These low-type surfaces have a low materials cost, generate little freight, and in construction methods and nature of equipment used are similar to grading operations, and so may be readily converted into the general group of excavation. In a similar manner the rigid types of surfacing have been converted into equivalent concrete pavement. Structures, which include bridges, culverts, railroad grade crossings, and safety devices, were reduced to three items: Reinforcing steel, structural steel, and structural concrete. The resulting final quantities per surfaced mile are shown in table 1.

TABLE 1.—*Final quantities per surfaced mile*

Year	Excavation				Surfacing					Structures		
	Excavation	Gravel [1]	Water-bound macadam [2]	Total excavation	Bituminous macadam	Bituminous concrete [3]	Brick [4]	Portland-cement concrete	Total surfacing	Reinforcing steel	Structural steel	Structural concrete
	Cubic yards	*Cubic yards*	*Cubic yards*	*Cubic yards*	*Square yards*	*Square yards*	*Square yards*	*Square yards*	*Square yards*	*Pounds*	*Pounds*	*Cubic yards*
1923	8,068	3,846	1,002	12,916	453	307	227	2,764	3,751	9,270	2,297	53
1924	8,364	3,792	1,237	13,393	391	351	137	2,960	3,839	12,374	2,258	67
1925	9,238	4,116	945	14,299	385	284	120	2,978	3,767	13,581	4,718	64
1926	11,068	4,695	837	16,600	405	215	103	2,452	3,175	14,070	3,629	68
1927	10,960	4,310	1,329	16,599	400	237	53	2,850	3,540	12,773	3,301	64
1928	12,545	4,050	757	17,352	692	273	86	3,297	4,348	17,075	4,953	65
1929	17,028	4,548	1,029	22,605	350	213	62	3,173	3,798	22,503	5,024	81
1930	18,946	4,426	797	24,169	345	247	92	3,640	4,324	26,852	7,750	122
1931	22,361	4,801	683	27,845	423	214	75	3,283	3,995	30,751	12,216	141
1932	18,423	4,874	692	23,989	429	218	76	3,332	4,055	29,243	10,807	102
1933	21,461	5,017	908	27,386	561	492	81	2,609	3,743	32,131	19,249	153
1934	28,270	6,163	684	35,117	515	508	42	1,360	2,425	29,963	21,733	158

[1] Includes sand-clay and topsoil.
[2] Includes treated and untreated macadam.
[3] Includes sheet asphalt.
[4] Includes all block pavements.

Base quantities and base prices (1925 to 1929) are shown in table 2. The base quantities and prices are the arithmetical averages of the quantities and prices by years for the base period.

TABLE 2.—*Average quantities and prices for the years 1925 to 1929, used as a base for computation of indexes*

Year	Excavation		Surfacing		Reinforcing steel		Structural steel		Structural concrete	
	Quantity	Price per cubic yard	Quantity	Price per square yard	Quantity	Price per pound	Quantity	Price per pound	Quantity	Price per cubic yard
	Cu. yd.		*Sq. yd.*		*Lb.*		*Lb.*		*Cu. yd.*	
1925	14, 299	$0. 386	3, 767	$2. 360	13, 581	$0. 0565	4, 718	$0. 0667	64	$22. 534
1926	16, 600	. 364	3, 175	2. 286	14, 070	. 0534	3, 629	. 0736	68	22. 760
1927	16, 599	. 352	3, 540	2. 291	12, 773	. 0510	3, 301	. 0707	64	22. 647
1928	17, 352	. 337	4, 348	2. 096	17, 075	. 0492	4, 953	. 0671	65	21. 216
1929	22, 605	. 316	3, 798	2. 055	22, 503	. 0481	5, 024	. 0591	81	21. 582
Total	87, 455	1. 755	18, 628	11. 088	80, 002	. 2582	21, 625	. 3372	342	110. 739
Average	17, 491	. 351	3, 726	2. 218	16, 000	. 0516	4, 325	. 0674	68	22. 148

The price index.—The method of computing the price index is shown in table 3. The composite mile on which the price index is based is composed of the average quantities of excavation, surfacing, and structures as determined for the base period 1925 to 1929. The average bid price for each of these items is shown for the years 1922 to 1935. The figures given in the amount columns are the costs of the average quantities at the prevailing rate for the year or quarter. The index figures give a comparison between the year or quarter and the base period 1925 to 1929. The results given in this table are shown in graphical form in figure 1.

The usage index.—The usage index shows the effect of changing practices in design features and use of materials in the highway-construction field. It is obtained by applying the average prices as determined for the base period to the various quantities of the base items used. The result shows how the cost would have varied because of changing usage had the unit prices remained constant. These changes in construction practices are shown in tabular form in table 4, and graphically by the usage trend in figure 2.

The cost index.—The cost index is obtained by combining the average annual quantities used, as shown in table 4, with the average annual unit prices that they cost. This index is shown in tabular form in table 5 and graphically by the cost trend in figure 2.

TABLE 3.—*Price trend in highway construction*

Year	Excavation [1] (17,491 cubic yards)			Surfacing [2] (3,726 square yards)			Structures								Composite mile	
							Reinforcing steel (16,000 pounds)		Structural steel (4,325 pounds)		Structural concrete (68 cubic yards)		Combined			
	Bid price [3]	Amount	Sub-index	Bid price [3]	Amount	Sub-index	Bid price [3]	Amount	Bid price [3]	Amount	Bid price [3]	Amount	Amount	Sub-index	Total amount	Index
Base period, 1925 to 1929	$0. 35	$6, 139	100. 0	$2. 22	$8, 264	100. 0	$0. 052	$826	$0. 067	$291	$22. 15	$1, 506	$2, 623	190. 0	$17, 026	100. 0
1922	. 40	7, 031	114. 5	2. 28	8, 488	102. 7	. 050	800	. 074	321	20. 18	1, 372	2, 493	95. 1	18, 012	105. 8
1923	. 47	8, 186	133. 3	2. 43	9, 047	109. 5	. 057	920	. 078	338	23. 37	1, 589	2, 847	108. 6	20, 080	117. 9
1924	. 43	7, 504	122. 2	2. 40	8, 950	108. 3	. 057	920	. 077	333	22. 91	1, 558	2, 811	107. 2	19, 265	113. 1
1925	. 39	6, 751	110. 0	2. 36	8, 793	106. 4	. 056	904	. 067	288	22. 53	1, 532	2, 724	103. 9	18, 268	107. 3
1926	. 36	6, 367	103. 7	2. 29	8, 518	103. 1	. 053	854	. 074	318	22. 76	1, 548	2, 720	103. 7	17, 605	103. 4
1927	. 35	6, 157	100. 3	2. 29	8, 536	103. 3	. 051	816	. 071	306	22. 65	1, 540	2, 662	101. 5	17, 355	101. 9
1928	. 34	5, 894	96. 0	2. 10	7, 810	94. 5	. 049	787	. 067	290	21. 22	1, 443	2, 520	96. 1	16, 224	95. 3
1929	. 32	5, 527	90. 0	2. 05	7, 657	92. 7	. 048	770	. 059	256	21. 58	1, 468	2, 494	95. 0	15, 678	92. 1
1930	. 30	5, 300	86. 3	1. 86	6, 949	84. 1	. 045	715	. 061	264	20. 08	1, 365	2, 344	89. 4	14, 593	85. 7
1931																
First quarter	. 30	5, 195	84. 6	1. 79	6, 666	80. 7	. 042	672	. 055	240	18. 90	1, 285	2, 197	83. 7	14, 058	82. 6
Second quarter	. 29	5, 072	82. 6	1. 77	6, 580	79. 6	. 041	658	. 051	219	18. 48	1, 257	2, 134	81. 3	13, 786	81. 0
Third quarter	. 27	4, 705	76. 6	1. 59	5, 924	71. 7	. 040	634	. 052	224	17. 49	1, 189	2, 047	78. 0	12, 676	74. 4
Fourth quarter	. 23	3, 988	65. 0	1. 56	5, 809	70. 3	. 037	594	. 056	244	17. 22	1, 171	2, 009	76. 6	11, 806	69. 3
1932																
First quarter	. 18	3, 166	51. 6	1. 52	5, 656	68. 4	. 036	571	. 049	211	15. 22	1, 035	1, 817	69. 3	10, 639	62. 5
Second quarter	. 17	2. 991	48. 7	1. 47	5, 481	66. 3	. 034	538	. 045	197	14. 98	1, 019	1, 754	66. 8	10, 226	60. 1
Third quarter	. 19	3, 358	54. 7	1. 35	5, 045	61. 0	. 033	526	. 043	184	14. 82	1, 008	1, 718	65. 5	10, 121	59. 4
Fourth quarter	. 19	3, 323	54. 1	1. 44	5, 377	65. 1	. 033	528	. 048	208	16. 28	1, 107	1, 843	70. 3	10, 543	61. 9
1933																
First quarter	. 20	3, 498	57. 0	1. 49	5, 552	67. 2	. 032	506	. 043	187	15. 44	1, 050	1, 743	66. 4	10, 793	63. 4
Second quarter	. 25	4, 338	70. 7	1. 58	5, 894	71. 3	. 035	552	. 043	188	14. 67	997	1, 737	66. 2	11, 969	70. 3
Third quarter	. 30	5, 194	84. 6	1. 74	6, 498	78. 6	. 041	657	. 049	212	17. 36	1, 180	2, 049	78. 1	13, 741	80. 7
Fourth quarter	. 29	5, 054	82. 3	1. 85	6, 904	83. 5	. 042	669	. 049	212	17. 12	1, 163	2, 044	77. 9	14, 002	82. 2
1934																
First quarter	. 30	5, 247	85. 5	1. 90	7, 079	85. 7	. 042	672	. 049	212	17. 82	1, 212	2, 096	79. 9	14, 422	84. 7
Second quarter	. 29	5, 072	82. 6	1. 98	7, 377	89. 3	. 042	678	. 051	221	17. 31	1, 177	2, 076	79. 1	14, 525	85. 3
Third quarter	. 29	5, 016	81. 7	1. 92	7, 161	86. 7	. 042	680	. 053	231	17. 98	1, 222	2, 133	81. 3	14, 310	84. 0
Fourth quarter	. 29	4, 988	81. 3	1. 82	6, 781	82. 1	. 044	712	. 057	245	17. 81	1, 211	2, 168	82. 7	13, 937	81. 9
1935																
First quarter	. 25	4, 460	72. 7	1. 90	7, 091	85. 8	. 044	699	. 051	219	17. 62	1, 198	2, 116	80. 7	13, 667	80. 3
Second quarter	. 26	4, 548	74. 1	1. 89	7, 031	85. 1	. 044	712	. 052	225	17. 51	1, 191	2, 128	81. 1	13, 707	80. 5
Third quarter	. 25	4, 355	70. 9	1. 88	7, 009	84. 8	. 044	709	. 052	224	17. 22	1, 171	2, 104	80. 2	13, 468	79. 1

[1] Common excavation plus other excavation items expressed as equivalent common excavation.
[2] Portland-cement concrete plus other surfacing items expressed as equivalent portland-cement concrete
[3] Indexes and totals were calculated with the bid prices carried to 1 more decimal place than that to which they are shown in this table.

TABLE 4.—*Usage trend in highway construction*

Year	Excavation [1] ($0.351 per cubic yard)			Surfacing [2] ($2.218 per square yard)			Structures								Composite mile	
							Reinforcing steel ($0.0516 per pound)		Structural steel ($0.0674 per pound)		Structural concrete ($22.148 per cubic yard)		Combined			
	Quantity	Amount	Subindex	Quantity	Amount	Subindex	Quantity	Amount	Quantity	Amount	Quantity	Amount	Amount	Subindex	Total amount	Index
	Cubic yards			*Square yards*			*Pounds*		*Pounds*		*Cubic yards*					
Base period, 1925 to 1929	17, 491	$6, 139	100. 0	3, 726	$8, 264	100. 0	16, 000	$826	4, 325	$291	68	$1, 506	$2, 623	100. 0	$17, 026	100. 0
1923	12, 916	4, 533	73. 8	3, 751	8, 320	100. 7	9, 270	478	2, 297	155	53	1, 174	1, 807	68. 9	14, 660	86. 1
1924	13, 393	4, 701	76. 6	3, 839	8, 515	103. 0	12, 374	638	2, 258	152	67	1, 484	2, 274	86. 7	15, 490	91. 0
1925	14, 299	5, 019	81. 7	3, 767	8, 355	101. 1	13, 581	701	4, 718	318	64	1, 417	2, 436	92. 9	15, 810	92. 9
1926	16, 600	5, 827	94. 9	3, 175	7, 042	85. 2	14, 070	726	3, 629	245	68	1, 506	2, 477	94. 4	15, 346	90. 1
1927	16, 599	5. 826	94. 9	3, 540	7, 852	95. 0	12, 773	659	3, 301	222	64	1, 417	2, 298	87. 6	15, 976	93. 8
1928	17, 352	6, 091	99. 2	4, 348	9, 644	116. 7	17, 075	881	4, 953	334	65	1, 440	2, 655	101. 2	18, 390	108. 0
1929	22, 605	7, 934	129. 2	3, 798	8, 424	101. 9	22, 503	1, 161	5, 024	339	81	1, 794	3, 294	125. 6	19, 652	115. 4
1930	24, 169	8, 483	138. 2	4, 324	9, 591	116. 0	26, 852	1, 386	7, 750	522	122	2, 702	4, 610	175. 7	22, 684	133. 2
1931	27, 845	9, 774	159. 2	3, 995	8, 861	107. 2	30, 751	1, 587	12, 216	823	141	3, 123	5, 533	210. 9	24, 168	141. 9
1932	23, 989	8, 420	137. 2	4, 055	8, 994	108. 8	29, 243	1, 509	10, 807	728	102	2, 259	4, 496	171. 4	21, 910	128. 7
1933	27, 386	9, 612	156. 6	3, 743	8, 302	100. 5	32, 131	1, 658	19, 249	1, 297	153	3, 389	6, 344	241. 9	24, 258	142. 5
1934	35, 117	12, 326	200. 8	2, 425	5, 379	65. 1	29, 963	1, 546	21, 733	1, 465	158	3, 499	6, 510	248. 2	24, 215	142. 2

[1] Common excavation plus other excavation items expressed as equivalent common excavation.
[2] Portland-cement concrete plus other surfacing items expressed as equivalent portland-cement concrete.

TABLE 5.—*Cost trend in highway construction*

Year	Excavation [1]				Surfacing [2]				Structures												Composite mile	
									Reinforcing steel			Structural steel			Structural concrete			Combined				
	Bid price [3]	Quantity	Amount	Subindex	Bid price [3]	Quantity	Amount	Subindex	Bid price [3]	Quantity	Amount	Bid price [3]	Quantity	Amount	Bid price [3]	Quantity	Amount	Amount	Subindex	Amount	Index
		Cubic yards				*Square yards*				*Pounds*			*Pounds*			*Cubic yards*					
Base period, 1925 to 1929	$0. 35	17, 491	$6, 139	100. 0	$2. 22	3, 726	$8, 264	100. 0	$0. 052	16, 000	$826	$0. 067	4, 325	$291	$22. 15	68	$1, 506	$2, 623	100. 0	$17, 026	100. 0
1923	. 47	12, 916	6, 045	98. 5	2. 43	3, 751	9, 107	110. 2	. 057	9, 270	533	. 078	2, 297	180	23. 37	53	1, 239	1, 952	74. 4	17, 104	100. 5
1924	. 43	13, 393	5, 746	93. 6	2. 40	3, 839	9, 221	111. 6	. 057	12, 374	711	. 077	2, 258	174	22. 91	67	1, 535	2, 420	92. 3	17, 387	102. 1
1925	. 39	14, 299	5, 519	89. 9	2. 36	3, 767	8, 890	107. 6	. 056	13, 581	767	. 067	4, 718	315	22. 53	64	1, 442	2, 524	96. 2	16, 933	99. 5
1926	. 36	16, 600	6, 042	98. 4	2. 29	3, 175	7, 258	87. 8	. 053	14, 070	751	. 074	3, 629	267	22. 76	68	1, 548	2, 566	97. 8	15, 866	93. 2
1927	. 35	16, 599	5, 843	95. 2	2. 29	3, 540	8, 110	98. 1	. 051	12, 773	651	. 071	3, 301	233	22. 65	64	1, 449	2, 333	89. 0	16, 286	95. 7
1928	. 34	17, 352	5, 848	95. 2	2. 10	4, 348	9, 113	110. 3	. 049	17, 075	840	. 067	4, 953	332	21. 22	65	1, 379	2, 551	97. 3	17, 512	102. 9
1929	. 32	22, 605	7, 143	116. 4	2. 05	3, 798	7, 805	94. 4	. 048	22, 503	1, 082	. 059	5, 024	297	21. 58	81	1, 748	3, 127	119. 2	18, 075	106. 2
1930	. 30	24, 169	7, 323	119. 3	1. 86	4, 324	8, 064	97. 6	. 045	26, 852	1, 200	. 061	7, 750	473	20. 08	122	2, 449	4, 122	157. 2	19, 509	114. 6
1931	. 27	27, 845	7, 546	122. 9	1. 68	3, 995	6, 696	81. 0	. 040	30, 751	1, 227	. 054	12, 216	655	18. 02	141	2, 541	4, 423	168. 6	18, 665	109. 6
1932	. 18	23, 989	4, 378	71. 3	1. 44	4, 055	5, 859	70. 9	. 034	29, 243	994	. 046	10, 807	499	15. 32	102	1, 563	3, 056	116. 5	13, 293	78. 1
1933	. 26	27, 386	7, 066	115. 1	1. 67	3, 743	6, 240	75. 5	. 037	32, 131	1, 195	. 046	19, 249	889	16. 15	153	2, 470	4, 554	173. 6	17, 860	104. 9
1934	. 29	35, 117	10, 184	165. 9	1. 91	2, 425	4, 622	55. 9	. 043	29, 963	1, 285	. 052	21, 733	1, 139	17. 73	158	2, 801	5, 225	199. 2	20, 031	117. 6

[1] Common excavation plus other excavation items expressed as equivalent common excavation.
[2] Portland-cement concrete plus other surfacing items expressed as equivalent portland-cement concrete.
[3] Indexes and totals were calculated with the bid prices carried to 1 more decimal place than that to which they are shown in this table.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

1936 FUNDS

AS OF MAY 31, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 2,604,320										$ 2,604,320
Arizona	1,781,347	$ 893,900	$ 675,911	59.2	$ 1,093,138	$ 921,221	42.3	$ 50,012	$ 19,640		164,575
Arkansas	2,142,723										2,142,723
California	4,756,959	564,411	326,307	9.5	4,957,583	2,834,811	116.3	2,602,530	1,496,657	62.1	99,184
Colorado	2,288,811	754,247	421,857	31.5	1,712,848	955,075	62.7	610,633	341,955	18.3	569,924
Connecticut	791,253				780,030	387,812	8.0	323,789	156,539	7.0	246,901
Delaware	609,375				439,748	219,874	34.4				389,501
Florida	1,655,723				831,120	415,560	27.5	268,640	134,320	8.7	1,105,843
Georgia	3,168,221				979,489	459,220	74.6	1,738,650	869,325	91.7	1,839,676
Idaho	1,531,162	351,681	199,729	60.4	1,535,349	916,660	111.9	283,672	162,749	16.4	252,024
Illinois	5,160,696	158,176	79,088	2.5	6,483,725	3,239,507	101.5	2,462,479	1,194,240	41.8	647,861
Indiana	3,087,613	845,419	421,740	29.5	4,772,580	2,386,205	167.9	241,094	120,510	4.9	159,158
Iowa	3,231,718	284,024	134,060	62.8	5,858,636	2,757,665	245.0	706,247	332,340	131.0	7,653
Kansas	3,317,054	208,591	104,295	187.2	2,751,463	1,375,732	172.7	4,085,702	1,825,518	478.4	11,509
Kentucky	2,304,143	667,119	330,805	42.6	1,495,589	732,800	99.1	1,450,355	690,897	37.7	549,641
Louisiana	1,776,939	214,279	107,140	7.3	1,957,491	978,745	68.7	1,018,497	509,249	31.6	181,805
Maine	1,090,167	211,352	105,676	4.3	1,500,980	750,490	49.3	191,524	95,762	4.1	138,239
Maryland	1,025,870										1,025,870
Massachusetts	1,741,877				333,935	166,968	3.1				1,574,909
Michigan	3,837,292	1,115,385	556,196	36.0	4,877,868	2,436,209	187.4	1,302,800	651,400	44.0	193,488
Minnesota	3,423,306	526,449	239,815	47.4	5,068,032	2,312,407	355.8	1,590,477	756,927	69.5	114,157
Mississippi	2,196,524										2,196,524
Missouri	3,800,856	1,100,172	549,003	221.2	3,203,835	1,601,917	136.8	2,849,812	1,424,819	88.6	225,117
Montana	2,560,449	743,868	416,359	142.1	3,032,832	1,698,082	204.5	707,263	395,997	79.5	50,011
Nebraska	2,581,663	1,098,358	549,099	66.5	1,115,073	576,899	127.1	929,663	464,832	127.7	990,833
Nevada	1,595,501	609,275	526,163	98.8	669,232	579,353	75.7	31,657	27,405	20.9	462,580
New Hampshire	609,375				748,375	367,840	22.2	141,629	70,736	1.9	170,799
New Jersey	1,675,751	87,925	43,962	1.0	2,030,222	1,015,111	28.9	1,321,388	574,164	10.4	42,514
New Mexico	1,999,299	583,962	355,094	62.3	2,129,748	1,295,312	121.7	542,230	339,164	18.8	9,729
New York	6,150,106	55,200	27,600	.1	10,633,475	5,258,735	191.8	1,113,955	556,977	9.4	306,794
North Carolina	2,938,657	197,121	98,561	37.1	1,674,113	834,591	236.8	1,939,522	953,203	193.3	1,052,302
North Dakota	1,960,162				187,005	101,941	.1				1,858,221
Ohio	4,565,435				4,760,772	2,315,087	65.2	2,301,792	1,020,808	24.1	1,229,540
Oklahoma	2,947,921	513,155	269,663	20.5	1,534,453	804,100	46.8	815,264	428,421	30.0	1,445,337
Oregon	2,044,633	341,519	206,184	14.4	2,993,539	1,744,551	91.5	122,949	66,767	4.4	27,131
Pennsylvania	5,348,062	100,109	49,786	2.2	6,767,002	3,383,501	99.9	1,447,456	722,532	19.9	1,192,243
Rhode Island	609,375										609,375
South Carolina	1,692,896				50,787	25,394		34,891	15,701	8.7	1,651,802
South Dakota	2,036,775				951,492	550,920	99.8	300,996	164,921	49.5	1,320,934
Tennessee	2,638,159	305,225	152,612	13.3	1,277,334	638,667	52.2	159,522	79,761	7.2	1,767,119
Texas	7,777,504	3,356,934	1,675,503	178.7	7,155,119	3,571,796	402.5	3,869,374	1,840,622	164.6	689,583
Utah	1,410,752	270,910	190,263	17.9	1,452,365	1,045,437	98.4	67,763	48,924	3.1	126,127
Vermont	609,375	22,052	10,786	2.9	1,159,127	579,564	54.1	28,646	14,286	2.4	4,739
Virginia	2,278,475	29,837	14,919	1.6	2,004,441	1,002,220	81.9	802,846	401,423	25.3	859,913
Washington	1,949,957	741,249	389,587	21.4	2,124,427	1,118,049	65.2	361,438	190,200	27.2	252,121
West Virginia	1,356,793	87,161	43,581	3.0	791,269	395,622	36.5	389,386	194,693	10.2	722,897
Wisconsin	3,045,557	511,344	255,672	18.9	2,379,194	1,187,004	86.7	2,554,529	1,248,665	91.9	354,216
Wyoming	1,559,444	952,899	586,437	110.9	1,573,069	948,306	163.7				24,701
District of Columbia											
Hawaii	609,375				267,058	131,547	3.5	177,989	88,565	4.6	389,263
TOTALS	121,875,000	18,503,308	10,113,453	1,615.0	110,094,962	57,018,507	4,521.7	41,939,061	20,691,614	2,070.8	34,051,426

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF MAY 31, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	
Alabama	$ 4,151,115				$ 3,067,503	$ 3,067,503	97.5	$ 560,971	$ 560,971	13.3	$ 522,640
Arizona	2,569,841	$ 700,390	$ 696,320	42.2	2,006,231	1,467,044	138.8	148,266	64,975	4.0	341,503
Arkansas	3,352,061	88,135	88,135	10.8	2,118,192	2,114,286	189.4	981,190	968,207	136.1	181,433
California	7,747,928	325,910	292,005	33.6	5,671,241	5,506,521	184.8	777,450	760,355	17.1	1,189,047
Colorado	3,395,263	408,119	408,119	33.5	1,378,555	1,378,164	52.0	58,855	58,855	2.5	1,550,125
Connecticut	1,418,709				274,047	252,390		82,024	81,225	.2	1,085,095
Delaware	900,310				445,795	445,795	39.6	93,390	93,390	19.3	361,125
Florida	2,597,144				2,001,384	1,983,511	72.3	284,788	284,788	11.2	328,844
Georgia	4,988,967	49,637	49,637	.7	383,705	383,705	28.3	303,348	303,348	19.3	4,252,277
Idaho	2,222,747	31,808	31,087	3.6	1,378,842	1,376,921	110.8	647,270	511,036	54.1	303,703
Illinois	8,694,009	241,980	241,980	9.2	6,127,765	6,127,765	313.6	1,498,420	1,498,420	125.1	825,844
Indiana	4,941,255	76,586	76,586	2.6	3,429,048	3,429,048	192.7	1,390,985	1,390,985	37.8	44,637
Iowa	4,991,664	63,000	59,100	30.1	2,451,695	2,329,915	225.4	1,010,633	956,900	103.9	1,645,749
Kansas	4,994,975	62,909	62,909	31.1	2,929,181	2,929,181	246.7	1,672,454	1,671,968	88.7	330,916
Kentucky	3,726,271	29,105	29,105	4.0	1,778,322	1,778,322	242.5	1,058,690	1,052,223	80.3	866,620
Louisiana	2,890,429				744,115	594,896	39.1	1,975,647	1,781,166	132.0	514,367
Maine	1,676,799	8,269	8,269	.5	1,009,106	1,008,558	43.9	567,443	567,443	25.0	92,529
Maryland	1,750,738				172,131	172,131	9.7	945,049	821,579	26.6	757,028
Massachusetts	3,262,885				117,754	117,754	1.1	71,042	71,042	1.4	3,074,089
Michigan	6,301,414	449,100	449,100	25.4	5,436,171	5,376,141	248.1	291,000	291,000	10.8	185,173
Minnesota	5,277,145	208,442	205,834	56.7	2,959,419	2,664,661	390.8	1,866,911	1,532,680	382.2	873,970
Mississippi	3,457,552	58,669	58,669	2.3	2,475,738	2,472,645	166.8	601,542	601,542	38.4	324,697
Missouri	6,012,652	382,553	382,553	180.1	3,280,826	3,280,590	485.8	1,691,627	1,689,526	117.0	659,984
Montana	3,676,416	194,813	194,813	9.4	3,078,597	3,078,597	169.1	356,657	356,657	7.0	46,349
Nebraska	3,870,739	7,994	7,994	.7	2,272,520	2,231,595	248.2	743,385	743,385	70.5	887,764
Nevada	2,243,074	669,447	652,447	24.1	941,539	918,969	40.7	76,563	76,563	9.8	595,095
New Hampshire	945,225				335,781	322,876	9.9	190,605	182,292	14.9	440,057
New Jersey	3,129,805				2,014,617	2,014,617	12.9	160,336	160,336	5.5	954,851
New Mexico	2,871,397	341,527	341,527	41.7	1,638,322	1,638,322	97.1	408,575	408,575	37.3	482,974
New York	11,046,377				9,311,728	8,899,928	127.3	1,174,660	1,174,660	33.2	971,789
North Carolina	4,720,173	183,120	183,120	20.8	2,587,629	2,555,040	182.3	710,835	626,320	29.3	1,355,693
North Dakota	2,867,245	162,637	162,637	20.8	505,899	505,899	64.6	1,355,255	1,355,255	162.1	843,455
Ohio	7,670,815	15,590	15,590	.3	3,895,734	3,831,134	43.6	988,555	940,181	94.6	2,883,909
Oklahoma	4,580,670	53,431	53,431	6.4	1,610,793	1,608,466	132.5	1,889,159	1,889,072	222.2	1,029,700
Oregon	3,038,642				2,205,493	2,193,484	93.2	620,647	537,339	68.7	307,819
Pennsylvania	9,347,797	35,092	35,092	2.4	1,093,587	1,031,928	33.3	1,361,332	1,357,294	73.4	6,923,483
Rhode Island	989,208	15,934	15,934		962,220	962,220	18.9	9,192	9,192	.2	1,863
South Carolina	2,702,012	47,193	47,193	2.4	798,132	765,650	79.7	1,210,780	1,205,363	109.2	683,806
South Dakota	2,976,454	152,013	152,013	88.1	1,258,006	1,257,976	228.3	554,190	554,190	70.1	1,012,275
Tennessee	4,192,460				1,660,053	1,660,053	67.7	1,158,796	1,158,796	46.8	1,373,611
Texas	11,939,350	860,755	766,946	96.0	9,576,366	8,800,302	818.3	2,191,588	2,049,531	187.6	372,571
Utah	2,067,154	163,709	163,543	9.8	991,883	976,551	86.8	434,574	385,086	39.1	541,974
Vermont	924,306	19,129	17,054	.2	648,118	572,492	13.4	348,659	316,794	9.1	17,966
Virginia	3,652,667	194,006	193,517	131.1	2,013,736	1,992,606	717.1	702,020	692,908	150.4	773,636
Washington	3,026,161	82,914	81,917	9.2	2,541,851	2,289,704	130.0	294,793	277,164	7.3	377,376
West Virginia	2,231,412				1,201,948	1,201,948	46.4	436,104	435,812	19.2	593,652
Wisconsin	4,823,884	113,268	103,038	4.1	3,506,289	3,163,135	205.4	1,750,130	1,556,956	120.3	755
Wyoming	2,219,155				1,748,480	1,748,465	103.2	233,673	233,668	26.0	237,022
District of Columbia	949,496	520,241	520,241	4.0	487,235	428,229	4.5				1,026
Hawaii	926,033				636,394	615,298	8.9				310,735
TOTALS	195,000,000	7,017,425	6,847,455	938.4	111,159,716	107,522,931	7,303.0	37,940,058	36,297,013	3,060.1	44,332,601

U. S. GOVERNMENT PRINTING OFFICE: 1936

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF MAY 31, 1936

STATE	APPORTIONMENT	COMPLETED		NUMBER		UNDER CONSTRUCTION		NUMBER		APPROVED FOR CONSTRUCTION		NUMBER		BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	Eliminated by Separation or Relocation	Protected By Signals or Otherwise	Estimated Total Cost	Works Program Funds	Eliminated by Separation or Relocation	Protected By Signals or Otherwise	Estimated Total Cost	Works Program Funds	Eliminated by Separation or Relocation	Protected By Signals or Otherwise	
Alabama	$ 4,034,617	$ 9,124	$ 9,124	1		$ 2,825,809	$ 2,825,809	27		$ 914,123	$ 914,123	9	5	$ 285,561
Arizona	1,256,099	47,412	47,412	1		951,552	823,340	9		124,309	106,387	1		278,960
Arkansas	3,574,060	191,070	190,975	4		1,013,452	1,009,839	23		1,326,136	1,323,317	24		1,049,930
California	7,486,362	22,330	22,330	1		6,108,326	5,864,147	35		1,330,681	1,326,739	21		273,147
Colorado	2,631,567					1,266,543	1,245,543	20		128,712	128,712	1		1,257,312
Connecticut	1,712,684													1,712,684
Delaware	418,239									143,486	120,000	1		298,239
Florida	2,827,883					1,476,880	1,474,569	13		387,794	387,794	4		965,519
Georgia	4,895,949					10,581	10,581			344,859	344,859	5		4,540,510
Idaho	1,674,479					852,091	852,091	12		121,445	108,758	2		713,630
Illinois	10,307,184					4,092,637	4,092,637	38		2,166,583	2,166,583	18		4,047,964
Indiana	5,111,096					2,222,383	2,222,383	19		2,288,562	2,288,562	12		600,151
Iowa	5,600,679	7,303	7,000	1		1,914,133	1,830,250	41		1,097,787	1,053,050	27		2,710,379
Kansas	5,246,258					2,517,667	2,517,667	28		2,770,181	2,728,591	30		
Kentucky	3,672,387					985,363	985,363	13		1,536,334	1,246,602	8		1,440,422
Louisiana	3,213,467					234,295	228,587	2		2,225,485	1,886,728	20		1,098,152
Maine	1,426,861					424,611	424,278	8		547,419	546,724	10		455,859
Maryland	2,061,751					292,968	292,968	3		639,813	617,344	4		1,151,439
Massachusetts	4,210,833					956,239	956,239	6		541,921	541,921	6		2,712,674
Michigan	6,765,197	121,850	121,850	1		4,973,252	4,973,252	37		820,350	820,350	9		849,745
Minnesota	5,395,441	21,950	21,950	1		1,742,914	1,736,864	38	1	1,066,234	1,066,234	19	8	2,570,393
Mississippi	3,241,475					1,582,321	1,582,321	34		412,052	412,052	8	1	1,247,102
Missouri	6,142,153					2,948,063	2,948,063	20		2,094,576	2,081,308	13		1,112,781
Montana	2,722,327					2,515,850	2,515,850	38		84,926	84,926	1		121,551
Nebraska	3,556,441					1,598,882	1,598,882	49		517,112	517,112	17		1,440,447
Nevada	887,260	86,337	86,337	2		621,949	621,949	8						178,974
New Hampshire	822,484					372,387	372,387	3		13,154	13,154		1	436,943
New Jersey	3,983,826					949,148	949,148	5		306,130	306,130	2		2,728,549
New Mexico	1,725,286	180,565	180,565	4		856,642	844,470	5						700,251
New York	13,577,189					7,069,964	6,809,418	22		2,632,090	2,631,810	8		4,135,961
North Carolina	4,823,958	10,268	10,268	1		1,211,295	1,211,295	14		835,468	835,468	12		2,766,926
North Dakota	3,207,473					396,659	396,659	9		413,748	413,748	15		2,397,066
Ohio	8,439,897					652,998	652,998	3		1,627,500	1,531,761	13		6,255,137
Oklahoma	5,004,711	12,408	12,408	1		1,406,310	1,406,310	27		1,029,266	1,029,266	15		2,556,727
Oregon	2,334,204					1,405,993	1,405,454	12		948,320	824,147	8		104,603
Pennsylvania	11,483,613					1,499,280	1,410,874	21		2,830,655	2,804,148	20		7,268,590
Rhode Island	699,691					654,008	654,008	4						45,683
South Carolina	3,059,956					1,074,270	1,067,966	22		317,409	317,095	9		1,674,895
South Dakota	3,249,086	51,774	51,774	1		707,011	707,011	14		141,286	141,286	8		2,349,016
Tennessee	3,903,979					365,701	365,701	9		363,383	363,383	10	7	3,174,895
Texas	10,855,982	34,420	34,420	2		4,511,049	4,319,574	55		3,766,712	3,495,834	47		3,006,154
Utah	1,230,763					462,506	462,506	6		279,548	259,448	3		508,809
Vermont	729,857					462,011	460,653	7		45,881	45,881	2		223,323
Virginia	3,774,287					1,090,993	1,020,129	20		621,997	621,997	24	7	2,132,161
Washington	3,095,041					1,722,370	1,717,570	19	1	310,628	310,597	7	6	1,066,874
West Virginia	2,677,937					108,323	108,323	1		659,969	659,969	5		1,909,645
Wisconsin	5,022,683	69,151	69,151	1		2,269,144	2,260,266	21		623,271	623,271	6		2,069,994
Wyoming	1,360,841	55,366	55,365	2		220,743	220,742	2		117,278	117,277	1		967,457
District of Columbia	410,804					170,643	170,643	2		253,264	238,616	1		1,545
Hawaii	453,703					296,218	295,333	3		215,430	158,369	2		1
TOTALS	196,000,000	921,328	920,929	24		74,064,427	72,922,910	827	2	41,983,267	40,561,431	488	35	81,594,730

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF MAY 31, 1936

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 14,378,514	$ 8,187,466	$ 2,816,248	736.2	$ 1,069,841	$ 160,296	$ 909,545	38.6		$ 479,385	2.9	$ 22,371	$ 54,664
Arizona	5,211,960	2,641,935	8,895,859	5,203,929	2,538,279	545.2	111,719		62,276	1.1				8,031	41,380
Arkansas	6,748,335	3,428,049	10,626,310	6,564,012	3,093,133	600.3	306,294	63,188	224,593	18.0	$ 21,152	63,198	2.3	99,983	47,124
California	15,607,354	7,932,206	28,560,858	15,589,248	6,928,687	741.4	2,064,841		953,278	19.0		820		18,105	49,421
Colorado	6,874,530	3,486,006	11,156,172	6,831,431	3,438,848	636.3	6,817		6,500					43,099	40,658
Connecticut	2,865,740	1,454,868	4,061,007	2,790,584	857,758	69.2	482,548		453,705	4.7				75,156	143,406
Delaware	1,819,088	923,395	2,643,857	1,819,088	782,660	128.3	88,530		88,530	.5		52,205	1.1		
Florida	5,231,834	2,661,343	8,485,965	5,187,944	1,994,276	294.9	562,346		526,291	14.0		55,876	.8	43,890	84,900
Georgia	10,091,185	5,113,491	11,958,542	9,128,958	2,335,866	678.0	1,434,362	379,753	1,006,585	69.8	384,612	665,307	73.4	197,862	1,105,733
Idaho	4,486,249	2,277,486	6,541,524	4,416,568	1,709,392	494.5	508,659		506,879	7.0	42,905	12,377		26,776	48,838
Illinois	17,570,770	8,921,401	22,493,796	16,147,212	5,597,651	623.6	4,586,193	1,274,935	2,992,129	71.2	3,837	19,238		144,785	312,383
Indiana	10,037,843	5,088,963	13,362,272	9,629,709	3,115,809	409.7	2,281,764	388,697	1,809,942	80.6		134,587	.4	19,437	28,626
Iowa	10,055,660	5,118,361	15,342,129	10,055,660	4,681,685	1,215.6	197,598		181,041	3.6		226,800	5.0		28,835
Kansas	10,089,604	5,117,675	15,149,328	9,932,696	4,857,804	1,115.8	387,954	107,706	245,161	17.7	5,871	5,140	.9	43,330	9,570
Kentucky	7,517,359	3,818,311	10,980,706	7,018,377	3,166,976	789.2	829,443	421,471	355,382	16.8	29,243	179,995	5.7	48,269	115,957
Louisiana	5,828,591	2,963,932	8,586,134	5,617,484	2,349,072	230.1	492,944	138,621	354,323	20.5	53,784	72,999	6.4	18,702	187,538
Maine	3,369,917	1,711,586	5,096,627	3,337,543	1,541,314	191.6	108,297		108,283	1.4				32,374	61,989
Maryland	3,564,527	1,810,058	4,473,059	2,899,421	624,669	114.5	1,081,343	552,686	516,805	36.5	30,000	222,668	9.1	82,420	445,916
Massachusetts	6,597,100	3,350,474	7,105,806	4,599,679	1,870,151	104.3	3,073,307	1,896,850	1,176,457	11.0		22,836		100,570	281,031
Michigan	12,736,227	6,452,568	18,695,878	12,538,651	4,816,677	682.6	1,790,175	163,400	1,568,797	85.7		30,825	.1	34,176	36,268
Minnesota	10,656,569	5,425,551	15,386,093	9,866,602	4,700,167	1,624.5	932,911	656,932	237,274	20.7	3,168	152,808	.6	129,867	335,302
Mississippi	6,978,675	3,540,227	11,624,100	6,557,815	2,221,201	664.2	1,624,012	330,980	1,224,067	79.7	6,555	51,836	1.3	83,325	43,123
Missouri	12,180,306	6,173,740	16,634,942	11,175,592	4,390,472	1,405.5	2,848,117	901,729	1,686,146	45.8		92,597	.4	102,985	4,525
Montana	7,439,748	3,769,734	10,975,765	7,173,669	3,138,022	1,005.2	668,314	159,632	492,278	27.4	57,745	98,365	20.2	48,703	41,069
Nebraska	7,828,961	3,964,364	12,435,684	7,725,872	3,432,884	995.4	781,732	65,535	506,111	42.4		11,397		37,555	13,972
Nevada	4,545,917	2,302,356	6,753,604	4,484,176	1,988,495	741.9	298,776	26,150	272,626	11.9		11,490	.7	35,591	29,746
New Hampshire	1,909,839	969,462	2,956,960	1,904,951	920,975	77.3	16,872		16,610	.4				4,889	31,877
New Jersey	6,346,039	3,220,879	7,073,060	5,986,387	727,336	76.7	2,485,327	175,941	1,992,453	10.6		303,276	6.6	183,711	197,814
New Mexico	5,792,935	2,941,700	8,514,329	5,624,747	2,667,109	761.6	186,670		175,678	2.0		8,561		168,189	90,352
New York	22,330,101	11,327,921	37,149,021	21,500,277	9,130,852	800.7	3,346,835	633,597	2,070,045	22.5	85,734	67,420	.7	110,493	59,604
North Carolina	9,522,293	4,840,941	14,391,598	9,044,715	4,125,439	1,325.0	515,195	75,589	427,711	16.1	179,281	205,439	13.5	222,709	82,352
North Dakota	5,804,448	2,938,967	7,324,784	5,436,458	1,227,275	1,959.7	1,034,194	181,402	772,738	133.0	17,146	377,958	47.6	169,442	560,995
Ohio	15,484,592	7,865,012	22,869,312	15,298,637	5,857,316	755.6	2,011,147	84,090	1,822,167	38.9	11,000	13,879	.3	90,865	171,650
Oklahoma	9,216,798	4,685,180	13,639,931	9,053,666	3,620,984	794.1	804,468	147,071	655,661	10.5		150,789	1.9	16,061	257,746
Oregon	6,106,896	3,097,814	9,503,408	5,970,497	2,659,625	462.0	492,704	64,950	332,215	6.4		38,544	.4	71,449	67,430
Pennsylvania	18,891,004	9,590,788	27,329,633	17,859,478	8,180,532	986.0	1,710,465	736,539	861,613	72.8	5,126	148,294	1.6	289,860	400,349
Rhode Island	1,998,708	1,014,572	2,982,260	1,998,708	850,540	88.0	151,901		150,183	1.1					13,848
South Carolina	5,459,165	2,770,954	7,240,911	5,213,787	1,827,521	586.1	558,305	34,110	502,236	29.2	125,330	219,597	11.0	85,938	221,600
South Dakota	6,011,479	3,047,643	8,456,446	5,731,526	2,167,147	1,471.0	665,341	28,392	636,949	61.0	81,536	133,788	23.6	170,025	109,760
Tennessee	8,492,619	4,302,991	12,447,422	8,298,288	3,247,894	473.5	1,165,557	191,703	877,453	19.1		10,343	.1	2,628	167,300
Texas	24,244,024	12,291,253	35,734,364	23,358,231	10,730,652	2,733.0	2,596,268	825,282	1,482,831	53.1		10,831	7.1	60,510	66,939
Utah	4,194,708	2,132,691	7,040,880	4,162,416	1,873,869	584.0	310,596		256,741	6.9	16,882		2.0	15,410	2,081
Vermont	1,867,573	948 007	3,032,652	1,863,531	842,013	137.6	114,167	3,922	95,623	2.4				120	10,371
Virginia	7,416 757	3,765,387	11,271,304	7,146,867	3,186,972	578.7	394,301	112,885	273,965	36.5	55,648	36,886	3.2	101,357	267,565
Washington	6,115,867	3,106,412	9,146,319	6,098,252	2,824,276	294.0	238,046		231,949	8.8	13,790	660		3,825	49,527
West Virginia	4,474,234	2,280,335	5,637,000	4,29[illegible],576	1,128,244	189.7	1,024,012	112,719	833,932	32.1	9,941	212,213	.9	54,999	105,945
Wisconsin	9,724,881	4,941,837	14,855,902	9,676,693	4,387,970	605.3	484,034	7,300	434,292	14.4		88,977		40,888	30,598
Wyoming	4,501,327	2,287,712	6,860,013	4,474,802	2,176,710	1,035.9	36,744	5,780	30,962	1.4		30,155		20,745	49,885
District of Columbia	1,918,469	973,842	2,645,015	1,909,584	735,296	20.0	222,699		187,199	2.3				8,885	51,348
Hawaii	1,871,062	949,778	2,308,775	1,774,496		44.0	1,012,501	82,369	914,171	11.5		14,000		14,196	21,607
TOTALS	394,000,000	200,000,000	582,815,830	378,162,956	154,084,743	33,677.5	50,197,186	11,192,202	34,500,381	1,338.6	1,240,286	4,734,359	251.8	3,404,556	6,680,517